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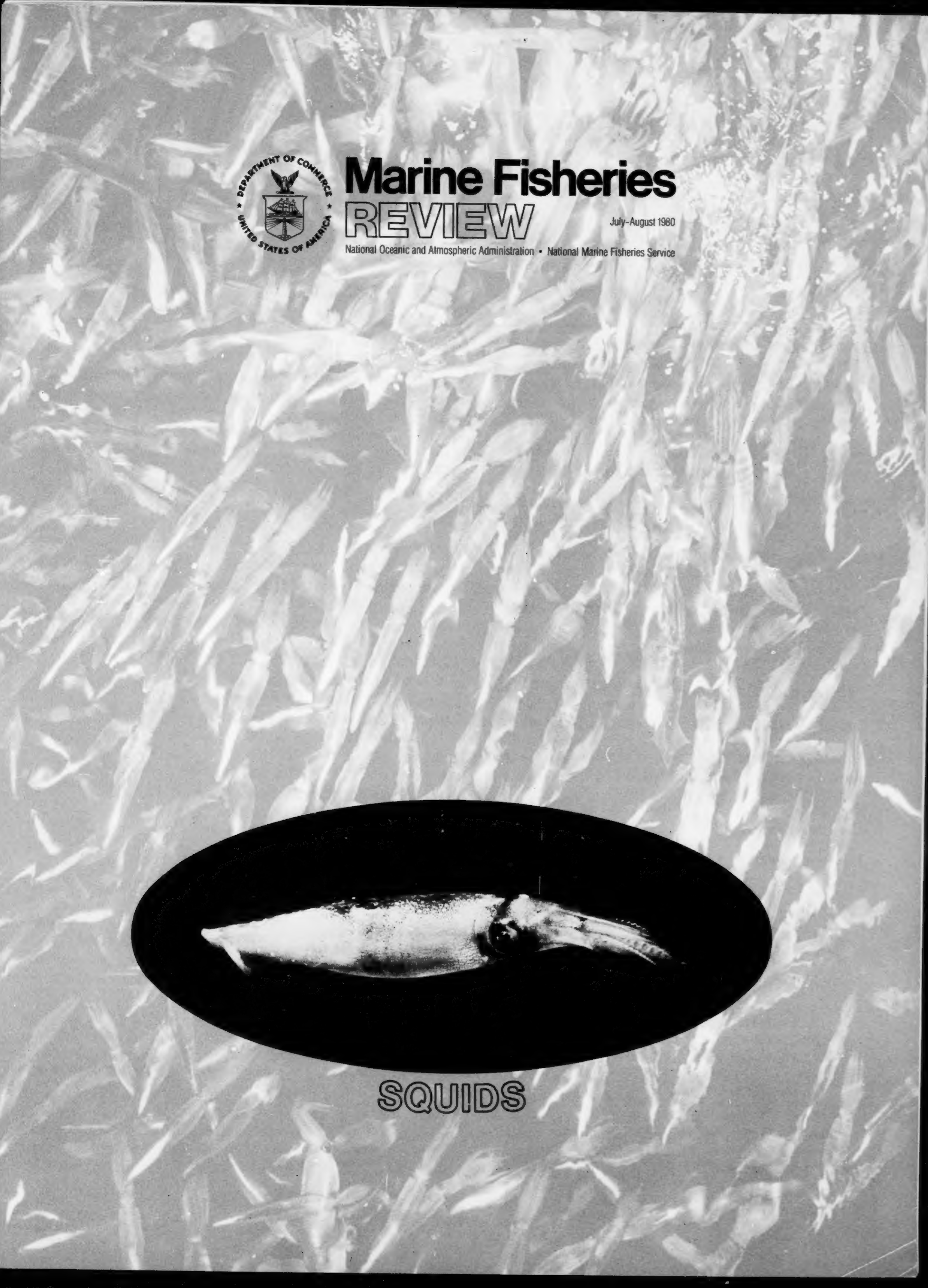
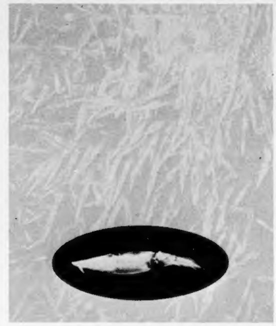


SQUIDS

Marine Fisheries REVIEW



On the cover: *Loligo opalescens*, background, by Glen Bickford, Calif. Dep. Fish Game; *Loligo pealei* by John Arnold, Mar. Biol. Lab., Woods Hole, Mass.

Articles

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Japan's Squid Fishing Industry

WILLIAM G. COURT

Introduction

Dried-squid (surume) has been an item of commerce, ceremony, and diet in Japan for hundreds of years, and squid is caught and is a popular food throughout the island nation.

Immediately after World War II, food shortages, a surplus of labor, and the low capital investment required for squid jigging stimulated the rapid development of the fishery. In 1952 squid landings reached 646,730 tons and, at 15 percent of the total, became Japan's most abundant landing.

Until the mid-1960's most landings were dried and much of the product was exported to China. Since then domestic markets have been developed for a wide variety of fresh, frozen, and processed products and demand has increased.

The main cause of worldwide developments in squid fisheries within the past decade has been the inability of Japan's squid fisheries to continue to meet this demand from waters adjacent to Japan. The overseas extension of Japan's squid fisheries and the rise of foreign squid fisheries to supply Japan's markets attests to this. Today squid resources are depleted in Japan's waters and the nation's overseas squid fisheries are increasingly restricted. Consequently, Japan's squid imports are increasing and its squid fishing industry is actively seeking and participating in joint ventures overseas.

What opportunities does Japan's squid market offer the U.S. fishing industry? Unlike salmon and crab, the major U.S. exports to Japan, squid is a relatively low-value item and it is widely available in the waters of nations with fishing costs considerably lower than those of the United States. Korea, Thailand, and Taiwan have established squid fisheries, a quality product, and good access to Japan's markets, and many other nations are actively developing squid fisheries to compete for that market. Consequently, increases in supply may hold squid prices down (Rodgers, 1979).

Also, Japan prefers frozen to processed imports and this discourages processing and the investment opportunities it offers. Furthermore, Japan is more interested in joint ventures or other access to foreign fishing grounds than in merely purchasing squid, and some nations are more disposed to such arrangements than is the United States. Thus the United States faces severe competition, and it will be difficult to establish squid markets in Japan. The following discussion attempts to introduce Japan's squid fisheries and markets and to provide some background against which to evaluate strategies for developing the U.S. squid fishing industry.

The Fishery

Japan's domestic landings have been decreasing since reaching a record high of 773,777 tons in 1968, and although *Todarodes pacificus* (Steenstrup) predominated until 1970, the composition of the landings has changed markedly since then (Fig. 1). Depletion of the *T. pacificus* resource was influenced by oceanographic changes, but it is now widely attributed to overfishing.

Increased catches by Japanese boats overseas have characterized the past 10 years. In 1977 this figure reached about 18 percent of Japan's total squid landings of 490,000 tons and continues to rise. Squid imports have been increasing since initiated in 1971, and in 1978 achieved a record high of about 100,000 tons, or 10 percent of the volume of total fishery imports.

In 1978 over 85 percent of the landings in Japan's waters consisted of *T. pacificus* and *Ommastrephes bartrami* (LeSueur). *Loligo pealei* (LeSueur) and *Illex illecebrosus* (LeSueur) from the northwest Atlantic, *Illex argentinius* (Castellanos) from Argentine waters, *Nototodarus sloani gouldi* (McCoy) from Australia, and

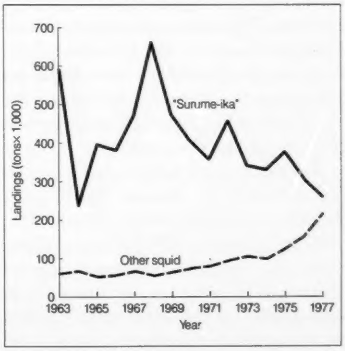

Figure 1.—Japan's squid landings, 1963-77. Solid line = "Surume-ika" (*Todarodes pacificus*, *Nototodarus sloani sloani*, etc.); dashes = other squid (*Ommastrephes bartrami*, *Loligo* spp., etc.).

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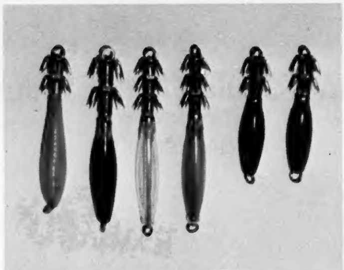
Nototodarus sloani sloani (Gray) from New Zealand constituted most of Japan's overseas landings. Imports were dominated by the same species with the exception of *O. bartrami*.

About 70 percent of Japan's squid landings are caught by jigging, a simple mechanized method which usually takes place at night when bright overhead lights attract the squid. Jigs, 6-cm lures with clusters of unbarbed hooks, are secured at 90-cm intervals on a monofilament line which is continuously lowered and raised with a jigging motion at depths of 30 m to more than 140 m. Squid, attacking the moving jigs, ensnare their tenacles on the hooks. The jigs shift to a horizontal position when reeled aboard, and thus the squid readily become disengaged.

The percentage of squid landed by jigging is declining; other fishing methods include use of drift gillnets, set nets, and bottom trawls. Most of Japan's squid fishing off North America, Argentina, and Africa, and some of that in home waters, is by trawlers. That off New Zealand is by a combination of trawlers and jigging boats. In 1979, jigging on a limited scale began off eastern Canada.

Trawling endangers both squid and other resources because it catches everything without discrimination and seems to damage small squid which escape through the mesh. Jigging catches only squid and exerts less pressure on the resource per unit of effort than does trawling. Therefore, as a resource management measure, the Canadian Government has reportedly considered encouraging the foreign boats fishing for squid within Canada's 200-mile zone to shift to jigging (Watanabe[1]).

Japanese squid jigging boats are divided into three classes: Small-scale, 1-30 ton; medium-scale, 30-100 ton; and large-scale, 100-500 ton. However, the Japanese system computes fishing boat tonnage at one-half to one-quarter of the value which would be assigned by standard classification



Typical Japanese squid jigs. Photo courtesy of the *Yamaha Fishery Journal*.

schemes. Most smaller boats are made of either wood or ferro-reinforced plastic while steel hulls predominate in those over 50 tons.

Since 1963, the proportion of landings made by jigging has changed markedly by size of boat. The percentage of landings by boats less than 3 tons and by 10-50 ton boats has decreased almost two-thirds and that of 3-10 ton boats has remained constant. The large-scale and 90-100 ton boats made less than 5 percent of the landings in 1963 and now account for over 50 percent of the total. These changes reflect the increase in the scale of the boats, the shift in the focus of the fishery from coastal to offshore waters, and the development of Japan's overseas jigging fisheries.

Of the approximately 30,000 small-scale boats which jig for squid, 86 percent also fish for other species. However, 42 percent of the medium-scale boats and all of the large-scale boats fish only for squid. The number of medium-scale boats has decreased to 2,300 in the past 6 years, but the number of 90-100 ton boats has increased. Of the latter, 646 or 77 percent are highly efficient, specially designed squid jigging boats. The number of large-scale boats has been fixed at 212 since 1973, but through license transfer their average size has increased annually. Most of these boats are former tuna long-liners, but recently several such boats have been designed and built specifically for squid jigging.

One of the most important pieces of equipment is the electric generator which, because of the high power demand of the squid-attracting lights, may have a capacity of as much as 300 kW on a 30-ton boat. However, many feel such bright lighting is unnecessary and wastes precious fuel. There are unenforced limits on the power of lighting, but gross violation is reportedly common. However, the Kudo Fisheries Cooperative Association in southern Hokkaido, the northernmost of Japan's main islands, has for 10 years limited its 10-ton boats to 15 kW, and this cooperative has one of the best landings and income records in the region.

Most boats over 90 tons and some of the smaller ones have freezing equipment on board. The 90-100 ton boats usually have a freezing capacity of 8-12 tons and the larger boats 10-17 tons per day, and an experienced crew must work a hard day plus overtime to freeze this amount. Virgin grounds with a limited number of boats could yield catches in excess of these quantities, in which case access to large-capacity shore-based freezing and storage facilities or other arrangements would have to be made. However, the catch per unit effort (CPUE) on the Japanese and New Zealand fishing grounds is not sufficient to make this a problem.

One of the 99-ton boats jigging experimentally off eastern Canada has been specially equipped with expanded freezing capacity. However, limited storage space on this size boat necessitates frequent trips to shore, thus reducing time on the fishing grounds and, in turn, efficiency.

The high costs of large-scale boats discourages their use by the coastal nation. Therefore a barge-mounted, highly automated freezing plant might be considered for use in conjunction with small- and medium-scale boats for the offshore fishery. Another application for a barge might be for preliminary processing at sea to avoid expensive land-based waste-water treatment and disposal problems. Some Japanese processors feel that this would require such a large barge and would entail so many logistical and other problems as to be unfeasible; however, one U.S. company is considering it.

[1]Hidenobu Watanabe, Managing Director, Ogura Fisheries Company, 2-7 Bandai Shima, Niigata-shi, Niigata-ken, Japan 950. Pers. commun.

Hokkaido has traditionally been a major focus of Japan's squid fishery, and the squid fishing industry is still centered in northern Japan. The Tsugaru Strait runs betweek Hokkaido and Aomori, the prefecture at the northern extremity of Honshu, Japan's main island, and connects the Pacific Ocean with the Sea of Japan. Strategic location on this waterway provides access to the major squid fishing grounds and is an important factor in the prominence of this area in the industry (Fig. 2). Hokkaido and Aomori, home of 38 percent of the medium-scale and 55 percent of the large-scale squid jigging boats, accounted for well over half of Japan's squid landings in 1978. Some 2,000 companies scattered throughout Japan process squid and it is the main product of 200 of these. However, production is concentrated in and around Hakodate, a port in southern Hokkaido; Hachinohe, Aomori's major port; and Ohata, an Aomori port on the Tsugaru Strait. Leading manufacturers of squid processing equipment and the major producer of automatic squid jigging machines are located in Hakodate and adjacent areas.

Figure 2.—Japan and adjacent areas.

The fishery for *T. pacificus* begins in May with fishing for small squid off western Kyushu and gradually moves northward as the growing squid swim toward the nutrient rich waters off northern and eastern Hokkaido. Areal differences in fishing seasons lead to interregional friction and competition as many boats from various parts of Japan follow the migrating squid. However, this practice is threatened by the difficulty of obtaining fuel supplies, especially for boats away from their home port.

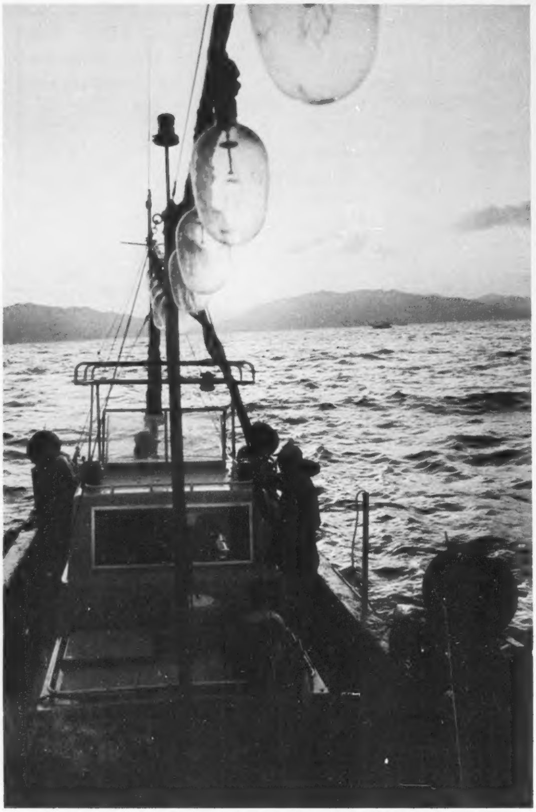
Initially, the squid jigging fishery was primarily a nearshore fishery by small boats, but with the automation of jigging and increases in the value of squid, boats were enlarged and fishing grounds extended. Until the late 1960's most of the larger boats fished in the Pacific southeast of Hokkaido. However, landings declined precipitously after 1968 and the focus of the offshore fishery shifted to the autumn subpopulation of *T. pacificus* in the central part of the Sea of Japan. In 1975 a jigging fishery for *O. bartrami* developed in the northwest Pacific east of Hokkaido and northeast of Honshu, and in 1978 this species accounted for almost half of the squid caught in Japan's waters.

In 1978 a major drift gillnet fishery for *O. bartrami* rapidly developed in the northwest Pacific. Initially most of the participants were salmon drift gillnet boats after the close of their season, but many squid boats soon joined them. The efficient new method soon began to threaten the livelihood of the squid jigging boats and opposition mounted. Jigging interests argued that they have a prior claim to and are economically dependent upon the fishery. Furthermore, they maintain that drift gillnetting of squid is: 1) Too efficient; 2) threatens recruitment by catching spawning squid which are low in value anyway; 3) causes waste as much dead squid is lost from the net; and 4) is often used as a cover for illegal salmon fishing.

On 1 January 1979 the Fisheries Agency, a part of the Ministry of Agriculture, Forestry, and Fisheries, prohibited drift gillnet fishing for squid north of lat. 20°N and west of long. 170°E, and some squid jigging interests are now appealing for a total ban on the fishery. However, over half the violations within the restricted area have been by licensed squid jigging boats and many others are participating. This situation has arisen partially because most squid jigging boats are operating at a financial loss. The drift gillnet boats have catch rates about ten times that of the jigging boats and considerably lower fuel consumption (Anonymous, 1979a). However, drift gillnetting is applicable to only certain species of squid.

Today the medium-scale jigging boats concentrate on the offshore Sea of Japan fishing grounds during spring and summer and late in the season shift to the Pacific to fish for *O. bartrami*. Some of the large-scale boats fish for *T. pacificus* in the northern part of the Sea of Japan, primarily within the Soviet zone, but their main fishing grounds are in the Pacific.

Winter is an idle period for most jigging boats in Japan's waters. To extend the amount of time fishing during a year, over half the large-scale and many of the 90-100 ton boats fish squid in the Southern Hemisphere between December and May. During the 1979-80 season about 269 of these boats were to fish near New Zealand and Australia: 113 are licensed to fish in New Zealand waters, and the remainder were to be



Fishing, sorting, and drying squids. Photos courtesy of the *Yamaha Fishery Journal*.

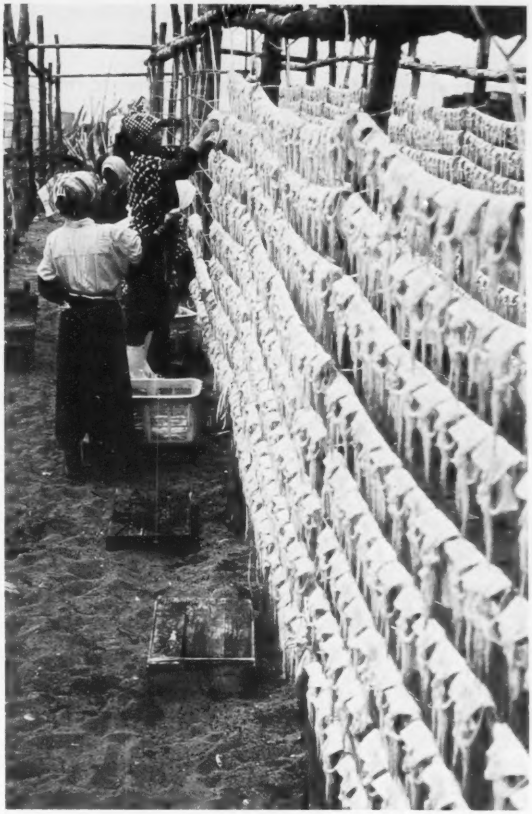
involved in joint venture test fishing (Anonymous, 1979b). Other boats were to fish off Equador and Mexico.

Access to foreign fishing grounds has traditionally provided Japan's fishing industry with both landings and a means to reduce pressure on heavily utilized domestic waters. Consequently, it has permitted a disregard for management of the resource. However, by reducing such access, the establishment of 200-mile zones has encouraged an emerging awareness among Japanese fishermen and fisheries administrators of the need for fisheries resource management.

Japan's squid fisheries are characterized by intensive fishing effort and thus by severe competition and marginal economic efficiency in both the domestic and international arenas. In the northwest Pacific, resource depletion, excessive competition, restrictions on operations and winter inactivity make a large number of Japan's 95-500 ton jigging boats eager to gain access to other squid resources. The round trip from Japan to Australia is 45 days and that from Japan to Newfoundland is 90 days, yet Japanese boats still seek access to these grounds. Some optimistic boat-owners dream of being able to jig off northeastern North America between July and December and off Argentina between January and June.

Regulation

The squid jigging fishery was unregulated until 1969 because the resource was abundant, but with declining CPUE, competition among the large number of boats gradually became a problem. In 1969 the large-scale, and 4 years later the medium-scale, boats were licensed by the Ministry of Agriculture and Forestry (it became the Ministry of Agriculture, Forestry, and Fisheries in 1978). Thus boats over 30



tons are regulated by the Fisheries Agency. In 1972, to reduce competition and interference between the various classes of boats, waters adjacent to Japan, including most parts of the Sea of Japan, were closed to the large-scale boats and jigging by medium-scale boats was prohibited in certain coastal waters.

The following year boats fishing in New Zealand were licensed. Also in 1973, as a conservation measure during the spawning season, jigging by boats over 30 tons was prohibited in Japan during March and April.

Since 1973 most boats between 5 or 10 and 30 tons have come under the regulation of prefectural Sea Area Fisheries Adjustment Committees or of the respective prefectural governors; the jurisdiction of these entities encompasses the coastal waters of the individual prefectures. Thus, in a pattern familiar in Japan's fisheries, regulations gradually forced the larger boats offshore or overseas in order to reserve the coastal waters for the smaller boats.

Unlike the Regional Fisheries Councils in the United States, Sea Area Fisheries Adjustment committees have neither the political power nor the geographic extent to enable them to become an effective instrument of fisheries resource management for most free-swimming species. Their main purpose is to arbitrate disputes concerning use of the fishing grounds. In other words, the function of these committees, and, incidentally, that of the Fisheries Agency as well, seems to be "fisheries management" rather than "fisheries resource management" (Keen[2]).

[2]Keen, Elmer A. 1979. Fisheries resource management — an assessment of the Fisheries Conservation and Management Act of 1976. San Diego State Univ., Dep. Geogr., San Diego. Unpubl. manuscr., 19 p.

Equitable, unified management of the *T. pacificus* stock is difficult to achieve because, as the squid migrate far along Japan's coasts and through the offshore waters of the Sea of Japan and the waters of South Korea, North Korea, and the Soviet Union, political and geographic division of both domestic and international jurisdiction strongly discourages if not precludes unified policy. Moreover, fishing seasons and the nature of the fishery vary from place to place.

Thus there is little incentive for resource management on the part of the individual prefectures because, while its cost would be borne by the individual prefecture alone, its benefits would be shared by all prefectures in common. Similarly, although Japan makes over 70 percent of the landings of the species, resource management incentive is diminished on the national level as well.

Differences in the degree of dependence of the various boats upon the fishery and the wide range in their size and capabilities further complicate regulation. Although fishing effort is excessive, the lack of alternative fisheries resources or other appropriate employment, plus the intractable questions of responsibility, cost, and equitability, challenge both the will and the attempt to reduce it. Thus fishing effort remains excessive, the resource is in a critical state, and the majority of the boats operate at marginal or submarginal levels.

Government fisheries policy has emphasized development and the maintenance of employment to the neglect of resource management, and an excessive number of boats is one of the major problems of the fishery today. The belief that it does not matter how much squid is caught, because, as it has a 1-year life cycle, it will die anyway, has influenced this policy. Thus the availability of low-interest government loans for investment in boats encouraged increases in fishing effort. The licensing system was imposed only after the number of boats had become excessive, and the ability to transfer licenses makes it even more difficult to reduce their number. Furthermore, the long experience as a "free" (unregulated) fishery persists in both regulation and practice. Thus, even after the decline in the resource had become evident, there was little conceptual motivation to stem the increase in fishing effort.

Associations representing the medium-scale and large-scale squid jigging boats have considerable political influence, and the sheer number of small-scale boats makes them a strong vested interest. Furthermore, the large amount of social and economic investment in the squid jigging fisheries compounds this inertia. Thus even if the government was resolved to reduce fishing effort, it would be an extremely difficult task. The Fisheries Agency thinks it advisable to reduce fishing effort, but refuses to subsidize it, both because great cost is involved and because such support is no more justifiable in the case of the squid fishery than it is in that of other fisheries suffering from excessive concentrations of fishing effort.

Severe restrictions establishing catch quotas, allowable gear, and fishing areas have forced reductions in Japanese fishing effort within the Soviet zone. The Soviet restrictions cause hardship to Japan's squid fleet, but are positive resource management measures. However, such policy is possible because it is imposed by an external entity which bears no responsibility to the affected fishermen and because, although the regulating authority owns the resource, it derives little benefit from the regulated fishery.

Consumption

After 1960, new processing techniques and the development of frozen seafood distribution chains stimulated the demand for squid and facilitated both wider product lines and new markets. Since 1973, increasing relative price has resulted in a 15 percent decrease in urban consumption of squid, but it is still higher than that of any other species. In 1977 per capita consumption of squid was roughly 4.65 kg (10.23 pounds) (round weight equivalent).

About 40 percent of the landings are marketed fresh or frozen, and "sashimi," finely-sliced uncooked squid eaten lightly dipped in soy sauce flavored with "wasabi" (Japanese horseradish), and "sushi," uncooked squid on bite-sized portions of vinegared-rice, are very popular items which constitute a major part of this demand. Fresh and frozen squid is often purchased for home consumption in various fried, roasted, broiled, uncooked, sauteed, and dressed forms.

A Japanese meal usually consists of numerous different dishes served so that each person at the table partakes of each dish in the amount and order that he or she wishes. Consequently, there is a demand for a wide variety of items which can be marketed in very small quantities and can be served either as sold or with little additional preparation. Many processed products meet this criterion and are frequently sold in packs as small as 50-100 g (1.8-3.5 ounces). In the past 10 years the number of processed squid products has increased greatly. Imported squid is used to produce many of these and some sources claim that such products are partially intended to "camouflage" the taste of the unfamiliar species.

Several products in addition to those already mentioned include: ika-moromi, squid pickled in miso, yeast, and rice or wheat; ika-mirin, squid pickled with red pepper and soy sauce; yaki-ika, roasted squid; ni-ika, boiled squid; koji-ika, fermented squid; Korean style shiokara, salt-fermented squid with ground hot-peppers; uncooked squid with herring or sea urchin roe; diced, boiled squid with kelp; ika-tsukudani, various boiled, soy sauce-flavored items; smoked squid; lemon flavored squid; ika-kamaboko and numerous other products made from squid-based fish-paste and other ingredients. Minor amounts of total landings are canned, salted, and smoked, and in 1977 about 14,000 tons was marketed as shiokara, salt-fermented squid. These are but a selection of the major products available, and there are many variations on, and combinations of, these items.

Almost 50 percent of total landings

are processed into a wide variety of dried and flavored forms. Surume (dried-squid) is produced by slitting the mantle, removing the organs and drying the mantle and tenacles either artifically or naturally. It is widely used for ceremonial purposes such as weddings and shinto festivals and as a raw material for further processing. Lightly roasted, manually torn into thin strips and served with a mayonnaise-soy sauce dip, it is hard and chewy like beef jerky and is often eaten with alcoholic beverages.

Saki-ika, which was developed in about 1960 to utilize the abundance of squid then available, is essentially a further processed version of surume. To produce it, squid is boiled to remove the skin and is then roasted, mechanically torn into thin strips, flavored, and sold ready-to-eat in plastic bags. Numerous variations on this product are available and have become very popular. In addition to being an accompaniment to alcoholic beverages, these products are widely used as general party foods and snack items, and much of their success lies in the convenience with which they can be marketed and consumed.

The Japanese have the highest per capita consumption of seafood in the world and a long tradition as a fish-eating people. Thus their fish handling, processing, and consumption patterns are highly refined and the average Japanese is aware of and insists upon degrees of difference in taste which the consumer in the United States does not even seem to recognize. Hence, the Japanese market has very sensitive color, flavor, and quality requirements. Furthermore, the Japanese are habituated to the flavor of local species. Squid is considered most delicious fresh and uncooked and is preferred served in this manner. Consequently, fresh *T. pacificus* and *Loligo* spp. bring the choice squid prices.

In mid-September 1979, fresh, high-quality squid sold on the wholesale Tokyo market for $5.00 per kg ($2.27 per pound). However, for several reasons United States or other foreign suppliers would receive a considerably lower price. Imported squid is neither fresh nor does it have the most preferred taste. Thus most of it is purchased as raw material for processing and therefore brings a relatively low price. Additionally, squid caught by trawl is slightly misshapen and below standard quality, and it often sells at 20 to 25 percent less than those caught by jigging. Depending on the species and other mentioned factors, the price may be further discounted. The tax on frozen squid is 15 percent, shipment from the West Coast costs $0.27 per kg ($0.12 per pound) and insurance, customs clearance, and middlemen add further costs.

Two examples may help to explain Japan's market. In Newfoundland in 1978, *Illex* squid, much of which was to be exported to Japan, sold for $0.176 per kg ($0.08 per pound) at the dock and $0.44 per kg ($0.20 per pound) to packers. The same squid later brought $1.27 per kg ($0.58 per pound) on the wholesale market in Japan. Considerable amounts of squid purchased in Argentina sold in Japan in the autumn of 1979 at a 29 percent discount for $1.12 per kg ($0.51 per pound).

The quality of the fresh and frozen product depends on careful handling from the moment the squid is caught until it is sold to the final consumer, and the Japanese market is far more demanding and rigorous than that of the United States. It took 3 years of negotiation, expensive mistakes, and mutual effort to establish effective squid handling practices in the export of Canadian *Illex* to Japan. Much training of and effort by U.S. fishermen and fish handlers will be required in order to meet the exacting Japanese standards. However, numerous trading, processing, and fish marketing companies, often working in combination, provide financial, technical, and supervisory assistance to a wide range of squid fisheries activities in other countries. Such efforts to insure a dependable supply of quality squid for Japan can provide markets, increase local prices, and stimulate fisheries development.

Certain sizes of squid are desirable, and shipments must be of similar-sized squid. Mixing of different sizes or slight deviations from the desired size lowers value, especially when selling on the fresh and frozen market. Furthermore, color, mantle-thickness, and degree of freshness determine value and potential use, thus both the type of squid and the stage of life when caught are important. High temperature rapidly spoils squid and rain discolors it, thus weather conditions at the time of harvest affect the quality and consequently the value of landings.

Differences between species traditionally landed in Japan and those domestic and foreign species which have recently come into prominence have forced changes in processing and consumption. Texture, flavor, size, and structure determine the potential uses of squid on both the fresh and processed markets. In the case of processing, it took expensive, major adjustments in technique and equipment to adapt saki-ika processing plants for the utilization of *O. bartrami*, and now that the transition has been effectively made, a large segment of the processor's market is dependent upon *O. bartrami* for raw material.

Similarly, horizontal alignment of mantle fiber is essential for such processing, but the *Illex* squid has vertical structure. *Illex* is also unsuitable for this type of processing because it does not yield the soft, fibrous texture and appearance which is required of the product. *Nototodarus sloani gouldi* from Australia has confronted marketing problems because of its large size, short tenacles, and poor yield when processed. Some of the Argentine *Illex* landed to date has been inferior because it was spawning or had spawned.

Squid consumption increases markedly in December and January in conjunction with Japan's protracted New Year's celebrations. Demand for surume is high at this time because of its traditional and ceremonial uses and, along with saki-ika and other items, because of the many parties and gatherings which occur during this festive period. Most of Japan's domestic landings are made between July and November and the amounts fluctuate widely between and within seasons and among the various species landed. Therefore, foreign suppliers must be

aware of the state and season of Japan's domestic market.

A distinctive feature of Japan's squid market is its ability to utilize both various kinds of squid and squid of different degrees of quality to produce a wide range of products. This enables successful use of several different sources of supply which yield both a variety of species and inconsistent quality. The highest quality product is sold on the retail or specialty market and a wide range of lower quality squid is processed. The very high unit price of one portion of a shipment enables the use of residual, low-quality squid for the production of low-value items. This helps explain why some imported squid sells at or below cost. However, the quality product usually brings a price sufficient to compensate for the extra handling costs involved.

Import Quota System

Squid imports were banned until 1970 because Japan's squid fisheries satisfied domestic demand until landings began to decline drastically after 1968. In 1971 a squid import quota system was established to permit limited imports. It protects domestic fishermen from foreign competition by regulating total squid supply in order to maintain a high market price.

Imported squid is classified into two categories and nine subcategories as follows: "Raw squid," which includes 1) live, 2) fresh, 3) frozen, 4) chilled, 5) salted, and 6) brine-soaked; and "dried-squid" which includes 7) dried, 8) smoked, and 9) prepared or preserved squid (canned, boiled, seasoned, salt-fermented, and preparations). Items 8 and 9 may be imported freely and import quotas have been established for items 1 through 7 (JETRO, 1979).

There are three categories of quotas, one each for processors, trading companies, and fisheries development. Their relative proportions vary each year and in 1979 were approximately 70, 25, and 5 percent, respectively. Although initially the quota was only for trading companies, the government later designated a quota specifically for processors in order to give them some control over supply and thus to preclude their domination by the trading companies. Thus the government controls both the amount and distribution of squid imports, and, to protect the business interests of those who deal in squid, it does not publicly disclose this information.

Altogether, 210 companies hold import quotas, sometimes as little as 10 tons apiece. However, major trading and fishing companies and their affiliates hold large blocks. As imports are limited, an import quota has value. Quota holders may realize this value through either control of that much of the market, sale (at about 5 percent of the sale price in Japan), or other transfer.

The Ministry of International Trade and Industry (MITI) administers the quota system and has the difficult and politically onerous task of establishing the amount of the quota. It attempts both to insure that the total supply will be sufficiently shy of demand to maintain a high value for domestic squid and simultaneously to recognize the interests of other participants in the market. The quota is set twice each year on the basis of estimated landings and may be adjusted subsequently as conditions warrant. The Trade Department of the Fisheries Agency's Marketing Division handles that proportion of the quota designated for processors and distributes it among their four national cooperative associations: One each for processors of dried-squid, delicacy foods, pre-cooked foods, and general fisheries products.

In administering the import quota system, the government weighs protection of the fishermen more heavily than the interests of the consumer. For example, in fiscal 1978, the estimated total domestic supply of squid, including the landings of Japanese-flag boats which fished overseas, was subtracted from estimated demand for the year and the import quota was set at less than 60 percent of the remainder (JETRO, 1979). Thus the planned deficiency in supply exceeded 40,000 tons, caused high domestic prices, and resulted in a decrease in squid consumption.

The United States and other countries on the one hand and processors and other groups in Japan on the other have been encouraging the Japanese Government to increase import quotas and to otherwise relax restrictions on squid imports. However, Japanese society traditionally protects established interests and the party in power derives political strength from a system of disproportionate representation in which the electorate in rural areas, including the fishing communities, plays an important part. Thus, although fishermen form but a small portion of the electorate, the present government is committed to protecting them and thus is reluctant to increase the quota enough to meet domestic demand. Hence, the import quota system supports a Japanese style modus vivendi whereby fishermen, processors, trading companies, and government administrators each participate in a regulated market. The consumer pays for the system and its administration through inflated squid prices and through taxes. Another factor in Japan which contributes to the high cost of squid and to the difficulty of changing the situation is the long, intricate network of middlemen between producer and consumer. Attempts to shorten and simplify distribution channels are meeting with limited success, but the impediments outlined above apply in this case as well.

Japan's import quota for squid has been increased for five reasons: 1) The *T. pacificus* stock has not recovered; 2) access to foreign squid resources has been restricted; 3) Japanese participation in joint venture squid fisheries overseas has increased; 4) the government favorably considers import quota requests from ventures involving Japanese boats; and 5) both foreign and domestic groups have been strongly pressuring the government to make such increases. However, the amount of the import quota is tied to domestic landings, and if landings increase sufficiently in the future, reductions in the quota could result.

In 1977, Japan's small import quota for dried squid was not all utilized, and therefore the amount was not increased the following year. The Fisheries

Agency's Trade Division reportedly would increase the quota and processors would purchase a competitively priced product if it were available.

Korea, Thailand, and Argentina and other countries export various dried squid products to Japan. Although dried squid produced in Newfoundland is exported to expanding markets in Hong Kong and Taiwan, exports to Japan have been limited, and in 1979 the poor dried-squid market in Japan foiled attempts to increase sales to Japan. However, various companies in Newfoundland are producing or planning to produce for the Japanese market, and several people on the U.S. East Coast are considering similar enterprises.

In 1978, Japan imported 118,000 tons of frozen and 4,000 tons of processed squid and cuttlefish. (Figures for the two items are frequently recorded together, thus individual values cannot readily be determined.) However, I estimate that about 80 percent of this amount is squid. The major exporters of frozen squid were Korea, Canada, Spain, Taiwan, and Argentina. United States squid exports to Japan totaled 1,909 tons and were almost exclusively frozen *Loligo opalescens* (Berry) from California. The United States ranked tenth among over 30 suppliers. Incidentally, in 1978, Japan caught 42 percent of the squid caught by foreign fishermen in the U.S. 200-mile zone, and 85 percent or 6,053 tons of Japan's catch off the U.S. East Coast was squid. Japan exported minor amounts of squid and squid products to the United States, mostly to supply ethnic markets in Hawaii and California.

Conclusion

Japan's international demand for squid is high and continues to grow, and traditional consumption patterns suggest that it might rise even further if some of the artificial price support mechanisms were removed. However, the combination of established suppliers, squid fisheries development by several nations which intend to export squid to Japan, and Japan's increasing overseas participation in joint venture squid fisheries make competition severe. Thus the extent and nature of international competition strongly recommend that development of a U.S. squid fishing industry should include the establishment of a domestic market to complement exports to Japan. If successful, this could insure sound development and future expansion of U.S. squid fisheries by providing accessible markets.

The preceding pages merely outline Japan's squid fishing industry, but plans to develop U.S. squid fisheries would benefit from detailed study of certain of its aspects. Several items might include: 1) Analysis of the advantages, disadvantages, and relative costs of each fishing method; 2) investigation of specific markets and marketing strategies for particular species of U.S. squid; and 3) evaluation of possible U.S.-Japan cooperative arrangements to develop the U.S. industry.

Joint enterprises with Japan might offer access to Japan's market and insure the cooperation of the Japanese Government; these two points are of paramount importance. Additionally, study of Japanese products and processing techniques might suggest ways to stimulate domestic demand in the United States.

Thus Japan's squid market offers an incentive to develop the U.S. squid fishing industry. Furthermore, over half of U.S. fisheries exports go to Japan and 88 percent of these are high-value items, but expansion of U.S. exports and, consequently, of the U.S. fishing industry depends upon exploitation of the underutilized species. Thus, attempts to export squid to Japan could yield valuable experience in marketing lower-value, underutilized species on our largest export market. This could later facilitate similar efforts with other available fisheries resources.

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Developments in South American Squid Fisheries

MARCELO JUANICO

The developments in South American squid fisheries depend on the conjunction of several factors, such as the general situation of the fisheries near the continent, the actual existence of squid resources, and the marketing possibilities of the product.

General Situation of Fisheries in South America

Table 1 shows total yields of each South American coastal country, as well as principal species and squid catches. Total yields of the continent decreased between 1970 and 1977, but these values only reflect the collapse of the Peruvian anchovy fishery ("anchoveta," *Engraulis ringens*); all the other countries have sustained or increased their catches.

Pacific Coast

Chilean landings stabilized in the last few years with an average of a little more than 1.1 million t/year, and traditional resources seem to be at their maximum rate of exploitation. Catches could be doubled with nontraditional resources; and bathypelagic fish, Antarctic krill, and continental slope resources could also be exploited (Arana et al., 1975). Up to now squids have been only a minor and scarce resource in the Chilean fisheries, recorded as "insignificant amount" in statistics. The commercially exploited species is *Dosidicus gigas* ("jibia," "calamar gigante," Humboldt squid) with a mantle length of up to 1 m and a weight of 35 kg. It is fished mainly in summer-fall along the north and central coasts of Chile, with purse seines or angling; occasionally, their shoals strand on the beach. It is used as bait, fishmeal, and, sometimes, as canned "squids in their ink" (20 t in 1971, Calbuco Port). Between 1963 and 1971 "jibias" landings were as follows:

1963: 2,700 t 1967: 300 t 1971: 124 t
1965: 145 t 1969: 53 t

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Table 1.—South American figures (metric tons) for total fisheries and principal species and squids. Data from FAO (1978). Data of 1978: Argentina (press statements of Government); Brazil (INFOPESCA, 1979b); Uruguay (Instituto Nacional de Pesca, 1979). (E = estimation, F = FAO estimation.)

	Year								
	1970	1971	1972	1973	1974	1975	1976	1977	1978
ARGENTINA Total	214,800	229,000	238,200	302,100	296,361	229,298	281,727	392,789	480,000
Argentine hake			102,800	151,400	162,200	109,000	174,906	273,630	330,000
Argentine anchovy			41,100	34,300	30,400	19,200	20,426	21,770	16,000
Short-finned squid			1,600	3,900	4,900	4,100	7,493	1,986	55,000
Common squids			100	200	200	140	128	255	250 E
BRAZIL Total	526,300	581,800	601,600	703,500	740,322	772,146	707,938	790,000 F	840,000
Sardinella			159,000	172,300	191,688	138,923	97,255	163,327	
Shrimps			56,800	53,900	57,200	62,470	93,899	93,899 F	
Common squids			400	500	181	397	848	848 F	
CHILE Total	1,209,300	1,505,900	817,500	691,000	1,157,053	929,452	1,406,490	1,285,316	
Chilean pilchard			131,700	187,500	391,053	231,772	355,362	596,656	
Peruvian anchovy			367,900	191,800	389,194	239,847	434,045	15,069	
Hake			66,900	46,500	43,483	32,433	29,639	36,534	
Squids			insig.	insig.	insig.	insig.	insig.	insig.	
COLOMBIA Total	54,500	37,700	110,700	105,300	62,418	66,575	75,107	75,107 F	
Characins (freshwater)			57,400	52,300	22,405	26,158	32,692	32,692 F	
Other freshwater fishes			25,400	20,800	14,829	15,917	18,745	18,745 F	
Pacific seabobs (Peneidea)			1,800	6,100	4,394	2,846	3,342	3,342 F	
Squids			insig.	100	123	100	24	24 F	
ECUADOR Total	91,400	106,700	108,200	153,900	174,400	263,400	315,000	475,500	
Pacific thread herring			55,200	95,000	110,000	175,000	225,000	383,000	
Skipjack tuna			5,500	6,000	8,500	12,000	13,000	15,000	
Marine molluscs			2,700	2,800	3,000	3,000	3,000	3,000	
PERU Total	12,534,900 F	10,528,600	4,725,200	2,328,500	4,144,858	3,447,490	4,343,125	2,529,995	
Chilean pilchard			6,300	132,300	72,605	62,851	174,701	870,899	
Peruvian anchovy			4,447,400	1,513,000	3,583,476	3,078,810	3,863,050	792,106	
Chilean jack mackerel			18,800	42,800	129,211	37,899	54,155	504,552	
Squids			720	300	133	466	1,092	275	
SURINAME Total	3,100 F	3,200	3,600	4,500	4,887	6,093	6,510	6,311	
URUGUAY Total	13,200	14,400	20,600	17,500	16,000	26,333	33,804	48,374	74,223
Hake			8,500	4,500	1,500	9,847	11,675	22,511	41,323
White croaker			2,800	2,800	4,000	5,594	9,434	11,920	13,980
Short-finned squid			200	200	100	520	773	362	2,182
VENEZUELA Total	126,400	138,900	152,200	162,400	150,085	153,407	145,731	152,234	
Round sardinella			45,400	47,500	22,835	47,608	36,733	35,752	
Ark clams			6,200	9,100	12,178	8,751	11,101	16,287	
Common squids			1,200	1,700	2,208	1,625	1,202	1,937	
SOUTH AMERICA (includes Bolivia and Paraguay)	14,796,000	13,167,000	6,801,000	4,494,000	6,775,000	5,920,000	7,340,000	5,783,000	
World total	71,000,000	71,000,000	67,000,000	68,000,000	71,000,000	71,000,000	75,000,000	74,000,000	

Since 1972, landings were smaller than 11 t/year. Landings averaging 15 t/year of another Chilean squid (*Loligo gahi*) were recorded between 1961 and 1965, but since then the amounts caught have been insignificant (García-Tello, 1965; Hancock, 1969; Nesis, 1970; Instituto de Fomento Pesquero, 1972, 1976).

Peruvian fisheries have been dominated by anchovy up to 1970-71 (11-12 million t/year). Even now, in spite of the reduction of total yields, squid landings are unimportant.

Polish trawlers probably fish "jibias" as by-catch of other resources off Chilean and Peruvian coasts, but no specific information is available (Lipiński, 1973).

Ecuador shows a similar situation for squids, and fishery statistics do not differentiate them from the other mollusks (Villón et al., 1970; Mora et al., 1976, FAO, 1978). 1972 seems to be the exception, when Ecuador's frozen squid exports were about 800 t, and there were 100 t for domestic consumption (Mora et al., 1976).

Squids are also not important in traditional small-scale fisheries in Chile, Ecuador, and Peru (Seminario Regional Sobre Pesca Artesanal, 1976; Nesis, 1970).

Colombian fisheries are dominated by freshwater fish, and here squids are also irrelevant.

Atlantic Coast

Argentinian total yields have been increasing in the last few years, being the goal of the Marine Affairs Secretariat (Secretaría de Intereses Marítimos) to catch 1 million t in 1980. At present the main fishery resource is the hake ("merluza," *Merluccius merluccius hubbsi*), and traditionally the second one has been the anchovy ("anchoíta," *Engraulis anchoita*). Until 1977 squids had little importance; the short-finned squid ("calamar," *Illex argentinus*) was hake's by-catch, and the common squid ("calamarete," *Loligo brasiliensis*) shrimp's and coastal fishery's by-catch. In 1978 the situation changed because some trawlers started to fish only short-finned squid, working at a greater depth than the usual 100-200 m for hake. In 1978, *Illex* took second place in the Argentinian fisheries with 55,000 t; there are no definite figures for 1979 yet, but it is estimated that landings by the Argentinian fleet that year will reach 100,000 t. There is no available information on the amount fished by foreign ships just off (?) the 200 mile limit. Up to now the Argentinian harbor is Mar del Plata (MP, Fig. 1) and the bulk of the fleet works northward from lat. 40°S, but hake seems to be fished at their maximum potential in this area; due to this problem, in March 1979 fishing was forbidden north of lat. 40°S to ships bigger than 600 m³ hold capacity (INFOPESCA, 1979c; press statements of the Argentinian Government). Argentinian fisheries will expand especially on the Patagonian shelf, where hake and squid are also found (Boschi, 1970); because of the characteristics of this area, ships working there must be bigger and the development of suitable ports will be necessary. *Illex argentinus* is a squid of up to 33.5 cm mantle length, which inhabits the shelf and upper slope between 80 and 800 m depth, and between lat. 35° and 54°S (Castellanos and Menni, 1969; Brunetti[1]). Palacio (1977) recently recorded three male *Illex argentinus* from the Brazilian coast, one of them as far north as Rio de Janeiro (RJ, Fig. 1), at 60 m depth. Because of the species habits and the hydrology of the area, it is probable that substantial amounts of this squid reach north of lat. 35°S, deep on the Brazilian continental slope.

Uruguay shares with Argentina a common fishery area in front of Rio de la Plata. In 1974 a Fishery Development Project began, which slowly allowed yields to increase, particularly those of hake. Short-finned squid is captured as by-catch of hake and it is seldom especially looked for by ships. In spite of that, "calamar" yields

[1]Norma Brunetti, Instituto Nacional de Investigación y Desarrollo Pesquero, Casilla 175 - Mar del Plata, Argentina, pers. commun.

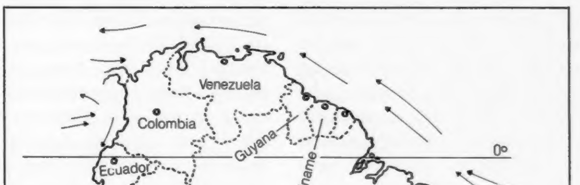

Figure 1.—Map of South America showing areas referred to in the text.

increased a great deal in 1978; it was estimated that they would reach 3,000 t in 1979. There is little local consumption of fresh squid, and the bulk of it is exported frozen to Japan, Spain, Brazil, and other countries.

Brazil finished its third Fishing Development Program in 1979, and a fourth was being projected. Yields increased markedly in the 1960's, but only slowly in the last decade.

The Brazilian coast is divided in four regions (south, southeast, northeast, and north); 80 percent of the industrial fleet works only in the south and southeast. Sardinella ("sardinha verdadeira," *Sardinella brasiliensis*) caught between Rio de Janeiro (RJ) and Santa Catarina (SC) is the main resource, but it is at or near its maximum rate of exploitation. The same holds for the shrimp fisheries of this region. Demersal fish are also an important resource on the southern Brazilian shelf, but during summer months—when the subtropical convergence moves southward—these stocks also move southward and catches diminish; these demersal fish are also heavily fished. The traditional lobster fishery at the northeast has already had overfishing problems, and the other resources of the area seem to be poor. The northern region has the biggest available biomass; however, the known resources have low densities and give low returns.

It is estimated that Brazilian yields could reach 1.4 to 1.6 million t/year; this expansion must be based on nontraditional fishing grounds and resources, including squids (Vazzoler, 1975; PDP, 1976; Yesaki et al., 1976; Mencía-Morales, 1977; INFOPESCA, 1979b). Squids (called "lulas" in Brazil, *Loligo brasiliensis* and *Doryteuthis pleii* principally) are not very important nowadays, and are caught mainly as by-catch of shrimp fisheries.

Venezuelan yields have been steady in the last few years. Squids (*Loligo pealeii* and *Doryteuthis pleii*) are principally captured as by-catch of shrimp fisheries and are not an important item (Voss, 1971; Griffiths and Simson, 1972) in spite of being abundant and having a good demand in the internal market (Ginés, 1975); they are sold fresh or as canned commodities.

South American Squid Resources

There are no resource evaluations or well based estimates of squids near the continent, and only some indirect and isolated data are available.

Along the Chilean coast, García-Tello (1965) stated that *Dosidicus gigas* is one of the dominant nektonic species of the southeast Pacific area; he does not give reasons for his statement. The Institute of Fisheries Promotion of Chile (IFOP) has been interested in this species (Hancock, 1969); however, it has not conducted any specific fishery survey on it. In this same area other fishery resources have been studied, but the fishing gears used were not suitable for squid and, as several authors state, low squid yields do not necessarily mean low quantities of them (Trujillo, 1972; Yáñez, 1974; Yáñez and Barbieri, 1974; Yáñez et al., 1974; Fernández, 1978).

Nesis (1970) studying the distribution of *D. gigas* off this coast between lat. 10°N and 35°S approximately in August-November 1968, stated that the major concentrations were between lat. 10°N and 18°S. Based on the same cruises, Zuev and Nesis (1971) recorded "vast concentrations" of this squid in the Peru Current. Lipiński (1973) following the above mentioned authors—and probably the experience of Polish trawlers—affirms that "huge quantities of the Humboldt squid (*D. gigas*) occur in the vicinity of Peru and Chile."

Studies on Ecuadorian demersal resources showed that squids (Ommastrephidae) are not important up to 300 m depth, as compared with hake and other fish (Loesch and Cobo, 1972). The comments made for the Chilean coast on the fishing gears used in the exploratory cruises are also valid in this case.

This author did not find more data about the area. Other papers on southeast Pacific squids give no specific information on their stocks (Nesis, 1973; Clarke et al., 1976).

Argentina, together with Germany and Japan, is making a thorough study of its fishery resources, and surely an estimation of the *Illex argentinus* stocks and some population parameters will be available. The results of the research cruises are still being analyzed (Brunetti, footnote 1).

Uruguay has also made some studies in its waters, but the results are not yet public. The *Illex argentinus* potential yield seems to be high (Lipiński, 1973).

Along the south Brazilian coast, research fishing surveys with trawls caught up to 1.5 t/hour of Loliginidae, but these good catches were scarce (PDP, 1976). Yesaki et al. (1976) suggested squids—together with two demersal fish species—as a choice during summer for the south Brazilian trawler fleet. However, there are very few data available to develop a fishing methodology and to assess the stocks. Studies with trawls and jigs off Sao Paulo (SP) and Santa Catarina (SC) showed almost no results (Sachet et al., 1974; PDP, 1974a, 1974b; Zenger et al., 1974; Agnes and Zenger, 1975). Juanicó (1979), studying Loliginidae between Rio de Janeiro (RJ) and Mar del Plata (MP), found that the two sympatric shelf species (*Loligo brasiliensis* and *Doryteuthis pleii*) seem not to be really mixed in the space, and that each of them would be made up by different populations or stocklets. The virtual presence of fishable quantities of *Illex argentinus* in deep waters off Rio Grande do Sul (RS) has not been studied.

Paiva and Cervigón (1969) put squids in tenth place among the species that could permit the expansion of the northeast Brazilian and Guyana area fisheries; the reasons for this statement are not given.

From Venezuela, there does not seem to be more information than "sometimes squids are very abundant," as it was mentioned before (Ginés, 1975).

South America as a Consumer Market

South America, with a population of about 240 million people, shows a paradoxical situation in which part of the population are malnourished (particularly in proteins), fish resources are abundant, and fish is only little consumed. This characteristic can be extended to the global Latin America (South America, Mexico, and Caribbean countries), where in 1970 "lived

Table 2.—Fish protein as a percentage of total protein consumed in South American coastal countries, 1970. Data from FAO, after May (1978).

Country	Fish protein (%)	Country	Fish protein (%)
Argentina	1.1	Guyana	11.8
Brazil	3.3	Peru	6.7
Chile	5.6	Suriname	18.2
Colombia	2.2	Uruguay	1.2
Ecuador	2.2	Venezuela	5.4

Table 3.—South American figures (1976, in metric tons), by countries, of seven commodities of aquatic animal origin. P = production, I = imports; E = exports; F = FAO estimation; WD = without data. Data from FAO (1978).

		Fish		Crustaceans		Crustaceans		
		Fresh, chilled, frozen	Dried, salted, smoked	and mollusks (fresh, frozen, dried, salted)	Fish products & prep.	and mollusks products & prep.	Oils & fats (crude or refined)	Meals, solubles, etc.
Argentina	P	169,300	4,400	4,800	23,100	1,800	5,600	21,400
	I	124	41	669	0	3	16	insig.
	E	96,427	1,655	3,223	739	149	insig.	3,765 F
Brazil	P	50,900	34,900	16,300	39,500	1,000	1,400	20,200
	I	57,200	19,396	217	1,480	17	205	250
	E	9,346	4	4,418	722	0	41	132
Chile	P	4,700	200	6,100	12,700	2,100	35,100	251,100
	I	100	0	0	300	0	0	0
	E	3,500	0	3,800	1,100	3,600	20,200	198,800
Colombia	P	2,200	11,100	WD	600	WD	WD	1,900
	I	31 F	WD	WD	4,608 F	WD	13,300 F	3,300 F
	E	463 F	WD	4,787 F	insig.	insig.	insig.	insig.
Ecuador	P	14,200	800	4,300	16,300	WD	6,400	42,700
	I	2 F	WD	WD	1 F	WD	6 F	insig.
	E	13,442	WD	4,309	11,138	insig.	4,851	30,143
Peru	P	57,700	5,700	1,000	32,400	WD	108,800	856,800
	I	insig.	insig.	0	300	0	0	insig.
	E	40,700	1,200	700	9,500	0	2,990	594,100
Uruguay	P	10,600	insig.	700	100	0	100	2,200
	I	41	2	8	197	3	437	insig.
	E	10,198	24	688	14	2	insig.	32
Venezuela	P	WD	6,300 F	4,300 F	21,000 F	WD	WD	7,600 F
	I	900 F	1,100 F	100 F	600 F	WD	200 F	8,200 F
	E	2,100 F	200 F	5,800 F	400 F	500 F	WD	WD

8% of the world population but accounted for only 4% of the world's fish consumption" (May, 1978). Luna-Muñoz (1978) stated that "the deficit of proteins in Latin America has been estimated in about 2 million MT/year, which represents as a whole some 20 million MT of meat." Table 2 shows that, except Suriname and Guyana (countries with small territory and population), fish proteins represented a small fraction of the diet in the South American coastal countries in 1970; this situation probably has not changed since then. Table 3 shows that in 1976 South American coastal countries, except Brazil and Venezuela, exported most of their fish production and did not import this kind of product.

There are several and complex reasons to explain this situation: 1) The bulk of fish production comes from industrial-scale fisheries, whose elaborate products are high-priced in developed countries; this is a strong stimulus to export. Besides, the lower income groups of the population cannot pay international prices. On the other hand, the South American countries urgently need the foreign exchange earnings of these exports. 2) In many places people are not accustomed to eating marine products, and avoid incorporating them into their diets. Often, the lower income communities are the more traditional and conservative in their feeding habits. 3) The countries of the area generally lack suitable marketing systems for sea products. This fact creates problems of low prices to fishermen, high prices to consumers, and discontinuous offering of products, not always of good quality. This marketing problem has been pointed out with emphasis in several countries: Latin America (May, 1978); Argentina (Malaret, 1973); Brazil (Mencía-Morales, 1977; Braga[2]); Perú (Ghersi, 1975); Uruguay (Brotos et al., 1978). The situation has been called to the attention of governments and international organizations. As a good example, the Inter-American Development Bank (BID) established a strategy which supports especially those projects of social and economic transcendency which are generally not very attractive to the private sector; this includes the creation of inter-regional distribution systems and assistance to traditional small-scale fisheries. Up to 1977, BID had supported the preparation of 16 Latin American fishery projects, and given loans of $83 million; if all these projects are set up, an increase of 31 percent of the present supply of fishery products for human consumption in the area is expected (Luna-Muñoz, 1978).

The future squid marketing in South America may develop within this context. Squid demand certainly will be related to fish demand, and probably the former will be more difficult to incorporate in the popular diet because of feeding traditions and appearance. Japan greatly increased its squid imports (the quota for the first 6 months of 1979 was 40,000 t) and will reduce by 5 percent the duties for this product from January 1980 on. On the other hand, the Japanese government claims that squid is a luxury product, and that stopping its importation will not affect the population's nutrition (INFOPESCA, 1979b, 1979c).

In July 1979, a Japanese Commercial Commission was searching for this mollusk in Argentina and Uruguay; they were mainly interested in top-quality frozen-on-board animals, because Japan is a demanding market in which squids are traditionally eaten raw. The present opening of the Japanese and other markets is a stimulus for export. Prices for the Uruguayan exports of short-finned squid frozen-on-land in 1978-79 averaged US $700-800/t FOB Montevideo (Instituto Nacional de Pesca, 1979; INFOPESCA, 1979a, 1979d); prices for frozen-on-board animals are higher than US$1,000/t. Brazil and Venezuela had imported some small amounts of squid, but this is an exception among South American countries, where the prices prove to be unsuitable for popular consumption. If South American squid yields overcome the

[2]Braga, I. B. 1978. Comercialização de pescado. Curso Fomento Pesquero, Instituto Oceanográfico Univ. São Paulo, Brazil, 16 p.

possibilities of exportation and if cheap and nonperishable products could be developed, this situation might change.

Conclusions

At present, the only important squid catches in South America are the Argentinian ones, and to a much less extent those of Uruguay. Estimates of squid potential yields near the continent will be available at short term only on this resource (*Illex argentinus*). Perhaps the south Brazilian trawler fleet could catch squids at short-term, but surely in smaller amounts.

The lack of suitable data on other South American squid stocks makes impossible estimating the feasibility of a future development of this kind of fishery. However, the available information points out the Peru Current "jibias" as a vitally important resource.

At present, South America is not a squid consumer and will hardly be one shortly. It does not seem probable that this continent will become an importer of squid products, even at middle-term.

Note

While this paper was in press, the author was informed about two research programs on squid resources on the Pacific coast[3]. Ecuador and Peru signed contracts with Japan, which is now making exploratory fishing surveys for squids along their coasts. The first results on distribution and yields will be available by the end of 1980.

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Recent Developments in the Squid, *Illex illecebrosus*, Fishery of Newfoundland, Canada

GEOFFREY V. HURLEY

Introduction

Since 1975 the nominal catches of the short-finned squid, *Illex illecebrosus* (LeSueur), in the northwest Atlantic have risen dramatically to a high of almost 100,000 t in 1978[1]. This increase was due in part to the worldwide development of fisheries for underutilized marine species such as squid. In 1976 the catch of *Illex* in the northwest Atlantic (65,000 t) represented 8 percent of the total world catch (800,000 t). Because of extended offshore fisheries jurisdiction, Canada recorded sales of offshore-caught squid worth $20-25 million in 1978. Newfoundland inshore fishermen have also reaped the benefits of strong foreign demand for squid as they earned $8-9 million in 1978.

The Newfoundland squid fishery has undergone many changes over the past century. Recent developments in this fishery regarding the management, harvesting, processing, and marketing of squid caught in Newfoundland inshore and offshore waters are discussed below.

The Resource

Life History

The short-finned squid is a summer migrant to inshore Newfoundland waters. They are thought to spawn offshore in the warm waters of the Gulf Stream since juvenile squid have been caught there in plankton tows in late April-early May[2]. Historically squid have been observed on the outer edge of the Grand Banks during May and June (Personal obs.; Mercer, 1973a; Mercer and Paulmier, 1974; Squires, 1957). Sometimes they have appeared inshore as early as May but more commonly in late June or early July. They migrated offshore again in October-November. While inshore they were found in water of between 5° and 20°C (Frost and Thompson, 1933; Personal obs.). Occasionally mass strandings have occurred on Newfoundland beaches. The strandings were thought to have been caused by entrapment of the squid in unfavorable environmental conditions or by predators (Lux et al., 1978; Templeman, 1966).

Squid occupy a rather unique position in the marine food web. They are prey for such species as the pilot whale, *Globicephala melaena* (Squires, 1957), bluefin tuna, *Thunnus thynnus* (Butler, 1971), and spiny dogfish, *Squalus acanthias* (Templeman, 1944), while they are predators on euphausids (Mercer and Paulmier, 1974) and such fish species as capelin, redfish, cod, haddock, mailed sculpin, and flounders (Squires, 1957). A complete review of the food and feeding of *Illex* in Newfoundland waters is given by Ennis and Collins (1979). They pointed out that observations on feeding were difficult due to maceration of food by squid before it entered the stomach. The squid grew rapidly during the inshore season in spite of the fact that a great percentage of the stomachs were found to be empty (Personal obs.; Mercer, 1965; Squires, 1957). By late season (October-November) the average mantle length approached 25.0 cm (9.75 inches) and the body weight approached 300 g (10.5 ounces), although there have been reports of individual squid caught in September of up to 1,100 g (38.5 ounces) (Doug Bradbury, H. B. Nickerson Co., St. John's Nfld., personal commun.). By late fall, females were found to have grown to a larger size than males (Squires, 1957).

Landings, Distribution, and Economic Value

The inshore landings of *Illex* in Newfoundland have varied greatly from year to year (Mercer, 1973b; Squires, 1957). Templeman (1966, fig. 62) presented a breakdown of squid landings for inshore Newfoundland into various processing categories up to 1964. Figure 1 brings this summary up to date (1965-78). Coincidentally the latter period corresponds to the widespread use of the more efficient Japanese mechanical drum jigger in the inshore fishery. Figure 1 shows that in some years the inshore catch was almost negligible (1968-70; 1972-74) while in other years, particularly since 1975, landings have increased substantially (to over 40,000 t in 1978).

Historically most squid have been caught along the northeast coast in Bonavista, Trinity, and Conception Bays and along the south coast in Placentia, Fortune, and Hermitage Bays (Templeman, 1966). Since 1965 the distribution of squid landings has

[1]Data from the joint Canada-USSR research cruise aboard the Soviet RV *Belogorsk*, 13 Feb.-4 June 1979. On file at Dep. of Fisheries and Oceans, Government of Canada, Halifax, N.S., and St. John's, Nfld.

[2]Unpublished data on file at Dep. of Fisheries and Oceans, Government of Canada, St. John's, Nfld.

ABSTRACT–Developments in the squid fishery in Newfoundland over the past few years have included noteworthy changes in the management, harvesting, processing, and marketing of squid. The implications of international involvement in the squid fishery and Canada's increased offshore fisheries jurisdiction are discussed.

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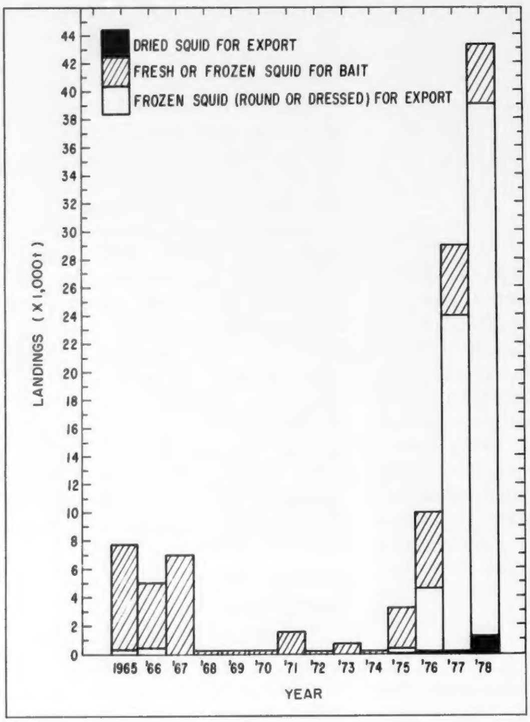

Figure 1.—Newfoundland *Illex* landings, 1965-78, by processing category.

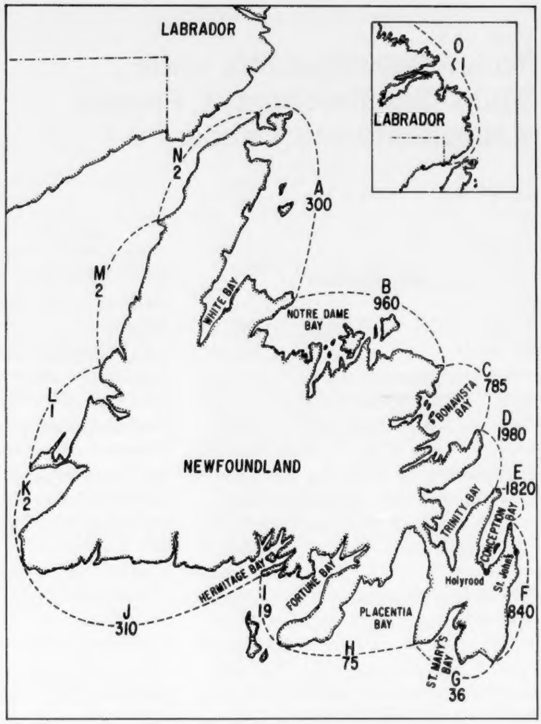

Figure 2.—Average *Illex* landings, 1965-78, by sea fisheries areas (in metric tons).

been much the same as in earlier years (Fig. 2) with the highest landings recorded on the eastern and southern coasts of the island from Notre Dame Bay to Hermitage Bay. The use of the landings to reflect the true distribution and abundance must be viewed with some caution.

Fishermen in some localities have only recently become interested in fishing squid for economic reasons. During the 1970's the landed value of squid in Newfoundland increased from $4,100 in 1976 to nearly $9 million in 1978 (close to 8 percent of total landed value of all marine species in Newfoundland). The unit price per pound of squid received by the fishermen rose from $0.03 in 1973 to $0.09 (from $0.07 to $0.20/kg) in 1978.

In years when landings were exceptionally high or low, the landings probably reflected abundance levels. In certain years, the Newfoundland *Illex* resource has been estimated to be on the order of several hundred thousand tons (Mercer, 1975). Squires (1957) could not detect any cycles of abundance; however, Templeman and Fleming (1953) suggested that hydrographic conditions may have been important in explaining the annual fluctuations in abundance. Since the life cycle of *Illex* is relatively short, 12-18 months (Mesnil, 1977; Squires, 1967), it is difficult to make year to year predictions of abundance. However, forecasts of inshore Newfoundland abundance of squid during July-November have been made from same-year offshore trawling surveys done in May-June (Hodder, 1964; Squires, 1957, 1959). The forecast index (Table 1) for the most part has been based on incidental catches of squid during annual haddock surveys along the southwest slopes of the Grand Bank and St. Pierre Bank. A short-term recruit survey has been used also in the Japan Sea to forecast abundance of the Japanese squid, *Todarodes pacificus* (Kasahara, 1975.) This preseason forecast has enabled the Newfoundland fishing industry to better prepare for the upcoming fishing season inshore.

Management Initiatives

The *Illex* stock(s) off the Canadian and American Atlantic coasts was originally managed as a unit by the International Commission for the Northwest Atlantic Fisheries (ICNAF). From 1975 to 1977 an open-ended TAC of 25,000 t was in effect for the area off the Canadian coast only, with 10,000 t to Canada, 15,000 t to the U.S.S.R.,

and 3,000 t to each of the other countries which participated in the fishery. Very few countries reached their quotas in 1975 and the total catch was only 18,000 t. However, due to high abundance of *Illex* and expanded markets, the catches rose to 42,000 t in 1976 and 80,000 t in 1977. In 1977 the establishment of the 200-mile fishing zone gave Canada jurisdiction over the management of all marine resources within this zone including *Illex*.

At Canada's request ICNAF provided advice on the management of *Illex* in 1978 and 1979. For 1978 a quota allocation of 100,000 t for the Canadian zone was recommended. Partitioning of this allocation allowed for 45,000 t to be caught in Newfoundland inshore and offshore waters (Grand Bank). A regulation of fishing effort in the offshore fishery was imposed to guard against over-exploitation in the event of a year of low abundance. Similarly, for 1979 the TAC of 120,000 t for the Canadian zone will be partitioned to allow for 50,000 t to be caught in the Newfoundland area.

The Inshore Fishery

The Newfoundland squid fishery has been conducted on the "squid jigging grounds" for over a century. This well-known fishery is steeped in folklore (Ronayne, 1955) and the presence of small boats 4-14 m (13.1-45.9 feet) long operated by one to four men is a familiar sight in coastal bays (Fig. 3).

Developments in Fishing Strategy

The jigger fishery has evolved from the use of a single homemade jigger on a line to the semi-automatic Japanese drum jigger (Fig. 3) introduced in the mid-1960's (Kasahara, 1965; Quigley, 1964) which has allowed for the use of numerous jiggers on a single line. The homemade jiggers were quite effective and varied from ordinary auto spark plugs (Fig. 4a) (usually painted red and used to attract squid over a type of lampara net which was then hauled aboard the boat) to molded lead jiggers with a single cluster of barbless hooks (Fig. 4b). The most common jiggers in recent use are made of durable plastic with a double cluster of barbless hooks. Some of these have a lead core and are used singly on a line (Fig. 4c) while the most popular solid plastic ones come in various colors and are used in series of up to 40 on a single line (Fig. 4d, e, f). The jigger fishery has been essentially a passive one, i.e., the boats anchored and waited for the squid to strike. Some successful attempts have been made to "actively" search for squid with echo-sounding equipment and to capture

Table 1.—Incidental early season captures of squid by the *Investigator II* on the Grand Bank, 1946-58, and reported occurrence of squid inshore (from Squires, 1957,1959).

Year	Dates fished	Total trawling time (hours)	Percentage trawling time in which squid were taken	No. of squid per 100 hours trawling	Squid landed (t)	Relative abundance
1946	May and June	81	10	385		Moderate numbers
1947	May and June	91	3	>70		Very abundant
1948	May and June	67	1	3		Scarce
1949	June	31	0	0		Few
1950	June	24	14	95		Moderate numbers
1951	May	21	42	5,683		Very abundant
1952	May and June	22	21	3,523		Abundant
1953	5-21 and 23-29 May 18-26 June	53.0	15.7	68	4,460	Abundant
1954	8-17 May 30 May-1 June 22-29 June	43.8	44.2	4,212	6,700	Very abundant
1955	17-23 May 13-19 June	34.3	26.2	1,024	6,700	Very abundant
1956	12-19 May 31 May-8 June 20-27 June	43.7	9.2	1,554	7,600	Very abundant
1957	19-24 May 11-15 June 25 June-1 July	35.1	11.4	330	2,680	Abundant
1958	30 April-8 May 18-24 May 25 June-1 July	44.0	4.5	30	890	Few

Figure 3.—Fishermen in small boats on the "squid jigging grounds" along the south coast of Newfoundland. Note the Japanese drum jiggers and rollers in each boat.

them with jiggers (Aldrich, 1964). Personal observations and discussions with fishermen indicated that echo sounders were able to detect squid adequately. The lower frequency signals were more useful because attenuation losses in deep water were reduced compared with the higher frequency signals. The detection of squid in inshore waters was best accomplished at night when the squid were found most commonly in midwater. An echo tracing of squid in inshore waters is shown in Figure 5.

Other types of fishing gear which have been tried successfully to capture squid inshore include modified cod and mackerel traps for which daily catches up to 5 t have been reported and purse seines, operated in conjunction with powerful overhead mercury vapour deck lights, which have caught up to 15 t in a haul.

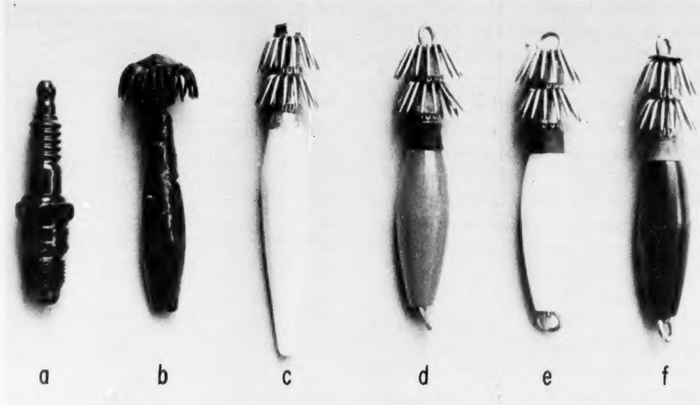

Figure 4.—Various jigs used to catch squid: a) painted spark plug used to attract squid over a dip net, b) homemade molded lead jig with a single cluster of barbless hooks used singly on a line, c) factory-made lead core plastic jig with a double cluster of barbless hooks used singly on a line, d), e), f) durable plastic jigs of various colors used in series on a line.

Factors Influencing Inshore Catch Rates

Squires (1957) stated that "even in years of greatest abundance it is probable that temperature, turbidity and other physical or chemical factors under the influence of local weather may cause sporadic appearances inshore in some areas." This seemed to be the case at Holyrood, Conception Bay (Fig. 2), in 1978. Throughout most of the fishing season, July-November, water temperatures approximated the preferred range for *Illex* inshore (7° -15 °C) (Frost and Thompson, 1933), yet daily catch rates varied greatly (Fig. 6). Squires (1957) suggested that wind direction may have been an important factor in influencing inshore catch rates. He observed that when the wind changed to an onshore direction, the "squid seemed to leave the vicinity and no more were jigged while the wind continued in this direction." It can be seen in Figure 7 that the highest catch recorded in 1978 was during offshore moderately strong southwest winds. However, a rather high catch was also recorded when the wind blew moderately strong from a northeasterly direction (onshore). Because both these winds parallel the axis of Conception Bay opening to the ocean (Fig. 2) they can cause the water to become turbulent within a very short time. Perhaps the turbulence forced the squid off the bottom and they were jigged more readily. Local fishermen often stir up the bottom with heavy chains particularly during daylight hours to achieve the same result. It can also be seen in Figure 7 that low catches were recorded when wind speeds from all directions were >60 km/hour (37.2 miles/hour). Perhaps high speed winds increased the turbidity of the water and obscured the jiggers. Since vision is important to squid while feeding (Squires, 1966), this may have

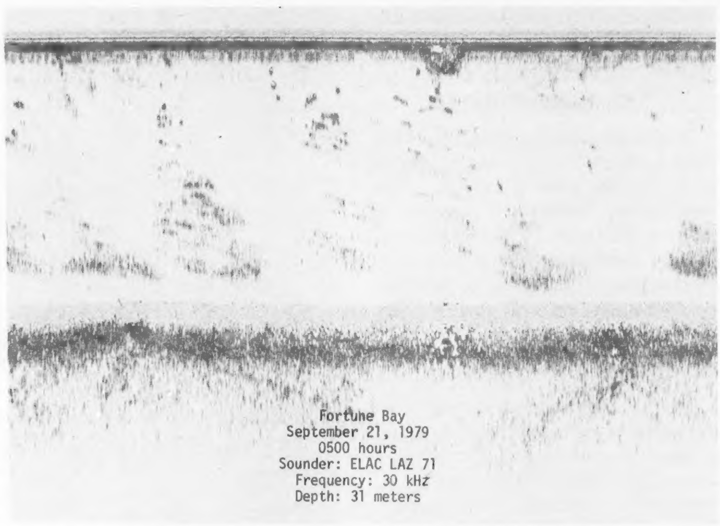

Figure 5.—An echo tracing of squid in inshore Newfoundland waters.

been a factor in the squid not being jigged. Also in very rough water fishermen often do not attempt to fish for comfort and safety reasons.

The Offshore Fishery

There is little information on commercial catches of *Illex* offshore on the Newfoundland banks. In 1978 nearly 4,000 t were taken in the offshore Newfoundland area (versus 55,000 t offshore Nova Scotia, Canada) by the fishing fleets of six foreign nations. Hodder (1964) and Mercer (1973a) reported that the highest catches of squid on the Newfoundland banks occurred in water temperatures >5 °C. Figure 8 shows a summary of bottom trawl catches and temperatures in depths ranging from 50 to 300 m (from 164 to 984 feet) during an offshore research cruise on the Newfoundland banks in June 1978. It is clear that the highest catches of squid were made in water warmer than 5 °C and that the optimal temperatures for finding concentrations of squid at that time of year were between 8 ° and 10 °C. There also seemed to be a diurnal periodicity in catches of *Illex* offshore similar to that reported by Froerman (1979) on the Scotian Shelf. Figure 9 shows that the highest percent of the catch by bottom trawls was made during daylight hours particularly from dawn to noon, while the greatest percentage of the catch by midwater trawls was taken during the dark hours of the day. Because of this diurnal vertical migration many commercial vessels that bottom trawl for *Illex* restrict their actual fishing effort to daylight hours only.

Because there were few Canadian-owned freezer trawlers to harvest squid offshore during 1978, the Canadian government allowed foreign-owned and operated freezer vessels to fish under contract to Canadian companies. Among the stipulations of these so-called "developmental charters" were that representatives of the Canadian fishing company be aboard during fishing operations and secondly that a certain percentage of the catch (25-50 percent) be processed onshore in Canadian plants. It was hoped that in this way the Canadian fishing and processing sectors would gain valuable experience in handling squid while at the same time product development and improved market access would be assured.

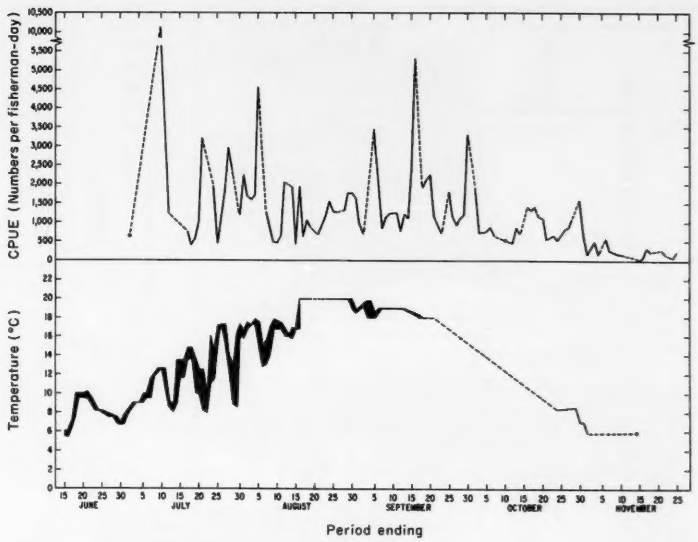

Figure 6.—Variability of catch rates in the jig fishery and bottom water temperatures (at a depth of 10 m) over the fishing season at Holyrood, Conception Bay. Dashed lines represent extrapolated values.

Processing and Marketing Developments

Historical Background

Over the past century *Illex* has been primarily an export commodity. Prior to 1950, large quantities of dried squid up to 700 t (1,543,220 pounds) (3,500 t or 7,716,100 pounds round weight) were exported mainly to Oriental countries for human food. The best markets were China and Hong Kong, although sales were also made to Singapore, Thailand, the Philippines, Burma, United States, Jamaica, Cuba, Trinidad, and the mainland of Canada. Until recent years the primary use of squid had been as bait in both the local and foreign (Portuguese, Norwegian,

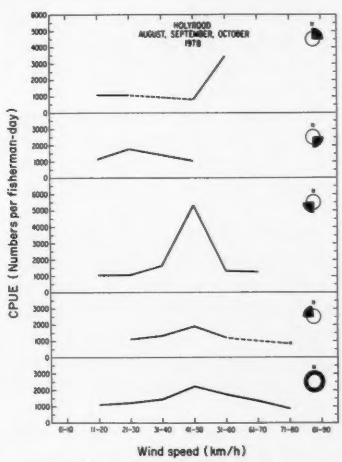

Figure 7.—Relationship of catch rates in the jig fishery and wind vectors recorded at Holyrood, Conception Bay, over the 1978 fishing season. Dashed lines represent extrapolated values. Pie diagrams indicate the wind direction quadrant(s) considered in each graph.

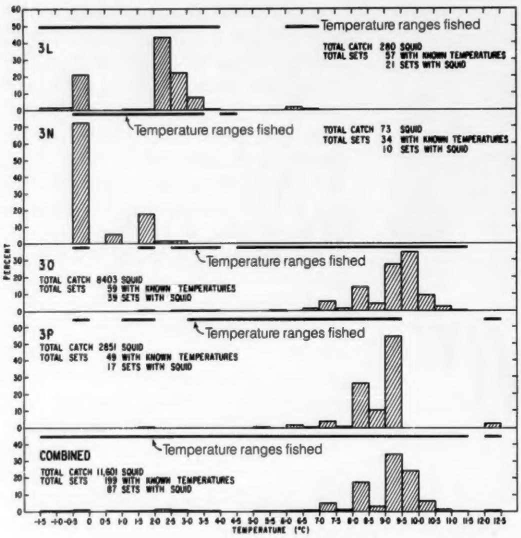

Figure 8.—A summary of bottom trawl catches of squid and water temperatures by ICNAF division (offshore on the Newfoundland banks) during a research cruise in June 1978.

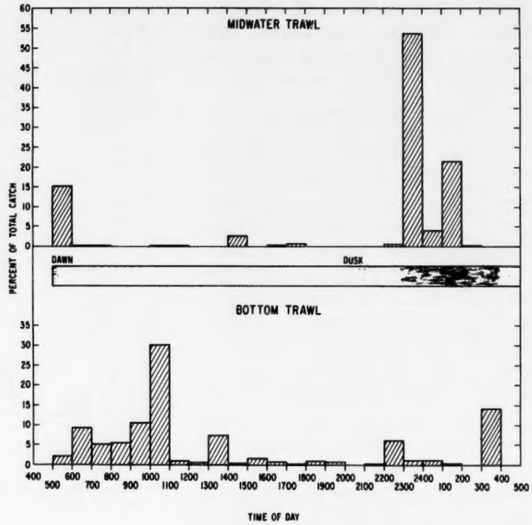

Figure 9.—A summary of the diurnal distribution of bottom and midwater trawl catches of squid during an offshore research cruise on the Newfoundland banks during June 1978.

and Faroese) line fisheries for cod in the northwest Atlantic. The government constructed bait depots, located in various ports around the island, for freezing and storing the squid. Most of these depots are still in use to serve the local line fishery for cod.

There were many reasons for the upsurge in sales of squid abroad for human consumption. Many fishing nations had lost their traditional far-seas fishing grounds because of the worldwide trend toward national jurisdiction over coastal fishing areas. With the universal demand for seafood, and the dwindling supplies of traditionally fished species, the cephalopods (octopus and squid) had been identified as a vast virtually unexploited resource (Gulland, 1971; Voss, 1973). The increased abundance of *Illex* since 1975 coupled with the decline in catches of the Japanese squid, *Todarodes pacificus*, during the 1970's (Okutani, 1977) gave rise to an intense interest in foreign supplies of squid, particularly by Japanese and eastern block countries.

The extent of foreign involvement in Canadian onshore processing operations has been substantial. Many foreign factory vessels have been contracted by Canadian companies to provide extra processing capability by docking alongside existing onshore plants. These "over the side sales" allowed fishermen to sell traditionally underutilized species such as squid, mackerel, and turbot during periods when Canadian plants could not handle them.

Frozen Squid

Japanese technicians, inspectors, and buyers have worked with Canadian processors and government researchers to produce the desired type and quality of squid products. For instance, Japanese quality control inspectors were placed in some Canadian plants processing squid in 1978 to inspect the packing and quality of the squid. This kind of cooperation helped to ensure that the proper transfer of processing technology would be made.

Since squid quality deteriorates rapidly after they are caught, laboratory experiments have been conducted recently by Canadian researchers to examine optimal methods of short-term storage of *Illex* (Botta et al., 1979). Results indicated that circulating chilled seawater, freshwater ice with plastic between the squid and the ice, and refrigerated seawater were satisfactory methods for preserving the sensory quality of the subsequently cooked squid. This kind of information is critical to the squid industry in Newfoundland as many squid at present are trucked long distances to plants for processing and deterioration of quality is inevitable.

Most of the squid processed in onshore facilities in Newfoundland were packaged round or as "tubes" in 10-kg (22-pound) boxes then flash-frozen in blast, plate, or sharp freezers. These boxes were shipped to major ports around the island such as St. John's where they were loaded aboard cargo vessels (Fig. 10) for transport to foreign markets.

Dried Squid

In 1978 there was a rejuvenation in the art of drying squid. Spurred on by

competition among a few entrepreneurs who secured access to Oriental markets, the price paid to fishermen for dried squid rose to \$2.42/kg (\$1.10 per pound) in 1978 and promised to exceed \$4.40/kg (\$2.00 per pound) in 1979. Nearly 500 t (1,102,300 pounds) (the equivalent of 2,500 t or 5,511,500 pounds round) were dried by fishermen and their families in 1978. Some women who spent the summer drying squid generated enough income to qualify for unemployment insurance over the winter. Squid was either dried on lines (Fig. 11) or on ordinary chicken wire stretched over a wooden frame (Fig. 12). In both cases the squid was "piped" or gutted, the head split open, the eyes and beak removed. If the squid was very fresh, it was soaked in fresh water for 5-10 minutes to prevent blackening when dried. Finally it was washed in salt and then fresh water to remove the slime and salt respectively. The squid required 3-4 days to dry completely and needed to be flattened by hand when they were about two-thirds dry. If squid are to be dried artifically, i.e., in a mechanical dryer or in a building, it has been recommended that they be given a final day's exposure to the sun in order to retain its palatability and desired color (Ewbank, 1937; Norm Haard, Memorial University of Newfoundland, St. John's. Personal commun.).

Some processors have expressed interest in specialized processing equipment such as splitting machines, cookers, skinners, and shredders. Further processing of squid would be advantageous since there have not been import quotas in Japan on fully processed products such as Daruma (skinned, seasoned dried tubes) or saki-surume (shredded dried squid) although a duty was paid on them. One product marketed locally with some success was a package of two lightly smoked tubes which were sold as a pub snack.

Figure 10.—A crate of 10-kg (22-pound) boxes of frozen squid is loaded aboard a foreign cargo vessel at St. John's, Newfoundland.

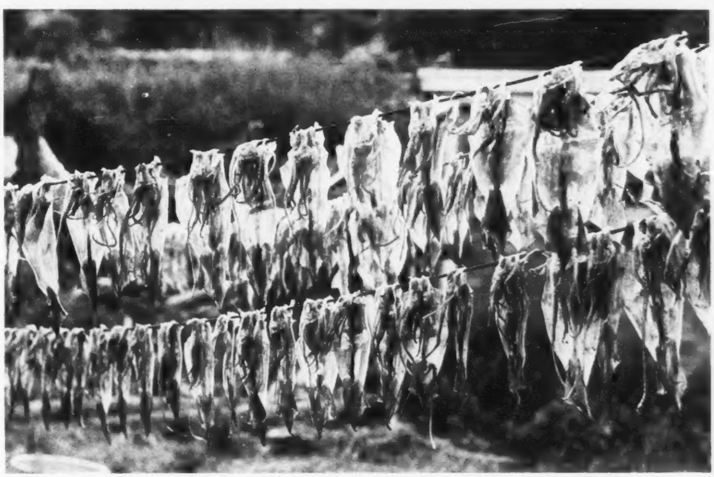

Figure 11.—Drying squid on lines.

Prospects for the Newfoundland Squid Fishery

The future development of the squid fishery in Newfoundland will depend on many factors.

Investment in the permanent expansion of the industry has been retarded by the lack of long-term forecasts of abundance. To date forecasts of inshore abundance have been made a few months before the onset of the fishery. At the very best this allows for lead time in arranging for the use of foreign freezer vessels as "developmental

charters" or as extended wharfage processing facilities. Also orders for packaging material for frozen squid and freight containers for dried squid have been made once the forecast was known.

Fishermen have become more experienced and innovative in their techniques for catching squid and the inshore fishery is evolving into a more "active" fishery in contrast to the "passive" one it has been for years. Increased Canadian participation in the offshore fishery will necessitate improvement in long-term storage capabilities on existing vessels and/or the aquisition of freezer trawlers.

Fishery managers will have to continue to make decisions based on reliable information concerning stock discrimination, status, and the causes of year-class fluctuations so that the resource can be managed in a rational way.

One of the biggest challenges facing the processing sector will be the attainment of desired quality standards for fresh, frozen, and dried squid. Increased sales of squid products will depend on the expansion and diversification of secondary processing capabilities along with improved access to foreign and domestic markets.

Figure 12.—Drying squid on chicken wire stretched over wooden frames.

Acknowledgments

P. Beck and J. Drew provided technical support for the collection and tabulation of the data. My appreciation for the efforts of H. Mullett, draftsman and G. King, photographer. F. Slade, Inspection Branch, Department of Fisheries and Oceans was consulted on the processing aspects of the paper. J. R. Botta and D. Taylor reviewed and criticized the manuscript.

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Biological Considerations Relevant to the Management of Squid (*Loligo pealei* and *Illex illecebrosus*) of the Northwest Atlantic

A. M. T. LANGE and M. P. SISSENWINE

*ABSTRACT–The general biology and distribution of squid (*Loligo pealei *and* Illex illecebrosus*) in the northwest Atlantic are reviewed based on previous literature and observations from research and commercial catches. Commercial catch and effort data from the Middle Atlantic area to Gulf of Maine inshore and offshore squid fisheries are presented as background for management. Research vessel catch per tow data provide indices for abundance, prerecruit indices, and stock size and biomass estimates.*

A dynamic pool model designed to simulate the effect of fishing on squid is presented. The instantaneous growth, fishing, and natural mortality rates were varied on a monthly basis, and spawning was simulated over an extended period. Recruitment was described by the Beverton and Holt stock-recruitment function.

Based on these models, the exploitation rates that will result in maximum sustainable yield (E_{msy}) are 0.40 and 0.37 for L. pealei *and* I. illecebrosus*, respectively, assuming moderate dependence of recruitment on spawning stock size. These models indicate a catch of 44,000 t of* L. pealei*, if annual recruitment of 1.5 billion individuals is maintained. Appropriate catch levels of* I. illecebrosus *varied from 21 to 95 thousand tons based on biomass estimates in recent years.*

Introduction

Loligo pealei (common or long-finned squid) and *Illex illecebrosus* (short-finned squid) are found in commercially exploited quantities along the northwest Atlantic continental shelf of the United States and Canada. This paper reviews aspects of the biology and population dynamics of these species relevant to the management of squid in this region. Catch statistics, research cruise results, and stock size estimates previously reported by Tibbetts (1977) are updated. For a more general discussion of the biology of *L. pealei* and *I. illecebrosus* see Summers (1969, 1971) and Squires (1957, 1967).

Until the mid-1960's squid supported only small domestic coastal fisheries along the coasts of the United States (1,000-2,000 t/year) and Canada (insignificant amounts to 11,000 t/year). Distant water fleet catches of squid along the U.S. coast have been reported since 1964. With the initiation of directed squid fisheries by Japan in 1967 and Spain in 1970 the catch increased rapidly to 57,000 t in 1973, but has declined since then to about 28,500 t in 1978 (Table 1). The catch of squid along the coast of Canada continued to increase through 1978 when it reached about 98,700 t.

The International Commission for the Northwest Atlantic Fisheries (ICNAF) set the total allowable catch (TAC) for both species of squid combined along the U.S. coast (ICNAF Subarea 5 and Statistical Area 6) at 71,000 t/year for 1974 and 1975, based primarily on a Japanese estimate of stock size of *L. pealei* (Ikeda et al., 1973). In 1976, ICNAF established a 44,000-t TAC for *L. pealei* and a 30,000-t TAC for *I. illecebrosus* after consideration of assessment documents by U.S. scientists (Au[1]; Tibbetts, 1977; Sissenwine and Tibbetts, 1977). In 1977 the ICNAF TAC's were set at 44,000 and 35,000 t for *L. pealei* and *I. illecebrosus*, respectively. These TAC's were included in the preliminary management plan for squid by the U.S. Department of Commerce, and adopted by the United States when extended jurisdiction began on 1 March 1977. The TAC's established in the U.S. 1978 and 1979 squid preliminary management plans were 44,000 t and 30,000 t for *L. pealei* and *I. illecebrosus*, respectively. These are also the levels set forth in the Fishery Management Plan of the Mid-Atlantic Fishery Management Council, which was put into effect in June 1979.

Biology

The loliginid squid, *Loligo pealei*, has been reported as far north as New Brunswick (Summers, 1969) but is primarily distributed from Cape Hatteras to Georges Bank (Tibbetts, 1977). *Loligo pealei* probably forms one stock which migrates on and offshore as much as 200 km seasonally, generally remaining in waters where the temperature is >8° C. *Loligo pealei* overwinter offshore along the upper continental slope (about 200 m deep) from western

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[1]Au, D. 1975. Considerations on squid (*Loligo* and *Illex*) population dynamics and recommendations for rational exploitation. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/61, Serial No. 3543, 13 p.

Table 1.—Annual squid catches[1] (*L. pealei* and *I. illecebrosus*) in metric tons, 1963-78, by country, from the northwest Atlantic, Cape Hatteras, N.C., to the Gulf of Maine.

Year	Country[2]															Total
	Bulg.	Can.	Cuba	Fra.	FRG	GDR	Ire.	Italy	Japan	Pol.	Rom.	Spain	U.S.A.	U.S.S.R.	Mex.[3]	
1963													2,104			2,104
1964													934	4		938
1965													1,153	177		1,330
1966													1,174	344		1,518
1967									7				1,251	1,411		2,669
1968			10						1,734				1,762	3,176		6,682
1969			1						7,711			566	1,461	1,340		11,079
1970						20			13,639			4,426	1,061	1,065		20,211
1971	90	1							10,602			6,770	1,182	6,138		24,783
1972	499		14	296	463			3,200	18,691	5,428	66	10,545	1,197	6,976		47,375
1973	410			820	1,641	313		3,165	15,526	9,199	150	14,932	1,635	8,977		56,768
1974	592	27						4,260	16,820	6,709	9	16,144	2,422	8,495		55,478
1975	205		151		27	898	4,745	4,274	13,985	6,836	48	9,902	1,728	8,928		51,727
1976	23	54	265		1,023	1,313	3,283	4,421	8,285	6,756	22	13,200	3,831	7,644		50,120
1977	60	20	34			9	23	4,185	12,690	888		13,438	2,112	8,010		41,469
1978								3,497	6,053		67	13,186	1,861	40	3,822	28,526

[1] 1963-1976 ICNAF (International Commission of the Northwest Atlantic Fisheries) Statistical Bulletins No. 13-26. 1977—ICNAF Summary Document No. 78/VI/28. Provisional Nominal Catches in the Northwest Atlantic, 1977. 1978—Preliminary, as reported to NMFS, by foreign fisheries officials.
[2] Countries are: Bulgaria, Canada, Cuba, France, Federal Republic of Germany, German Democratic Republic, Ireland, Italy, Japan, Poland, Romania, Spain, United States of America, Union of Soviet Socialist Republics, and Mexico.
[3] Mexico did not fish in this area prior to U.S. extended jurisdiction.

Georges Bank to Cape Hatteras (Summers, 1969). About April, larger mature *L. pealei* move inshore as far north as Long Island. United States commercial catches from southern New England (1973-77) indicate that large (>28 cm, dorsal mantle length) individuals arrive in the Massachusetts area by late April and early May. Smaller (<20 cm) individuals arrive by summer in much greater numbers.

The greatest number of eggs are spawned during May and hatch in July (Summers, 1971). Size differences in young-of-the-year and observations of ripe adults from samples of U.S. commercial catches in southern New England in July and from autumn groundfish survey cruises (Grosslein, 1969) in September, indicate an extended breeding season of about 6 months (April to September).

The life span of *L. pealei* was estimated by Summers (1971) to be 14-24 months with a maximum length of 18-28 cm (dorsal mantle length). However, he did find that some males survive to about 36 months and grow to > 40 cm. There may be a significant number that survive two spawning seasons, as seen in April 1973-74 where over 20 percent of the U.S. commercial samples were 30 cm or over and presumably about 1½ years old. It is not known whether these individuals spawned in their first season.

Mesnil (1977) has suggested a complicated crossover life cycle that is related to this extended spawning season. He hypothesizes two overlapping reproductive cycles for *L. pealei*, with maturation occurring over the winter and spawning occurring in April-May or in August-September. Those squid spawned in spring hatch in June, mature during their first winter, and spawn during late summer of the following year (at about 14 months). Their progeny, those spawned in late summer, hatch in September, are too young to mature over the first winter, and spend the next spring and summer feeding and growing. This group matures during their second winter to spawn, as large individuals, early in the spring. Mesnil based this proposed cycle on analysis of length frequencies and growth and maturation patterns observed in samples of *L. pealei* from four research cruises conducted in 1973, 1974, and 1975, as well as from known behavioral patterns of European squids.

Our observations of mature *L. pealei* and egg clusters in May support the occurrence of spring spawning. Young-of-the-year from the May spawned group, according to Mesnil, were represented by 7-9 cm individuals taken in September, indicating monthly growth of 1.7 to 2.0 cm. A subsequent mode, observed 2 months later at 11 cm implies growth at 1.0-1.5 cm/month after September, while an associated mode at 13-15 cm in May of the following year, indicates a 0.4-0.6 cm monthly growth increment during the winter months. Mature individuals of both sexes, which would probably spawn late in the summer initiating the second cycle of the proposed scheme, were present in this last mode. United States commercial length frequencies (Fig. 1) exhibited modes similar to those described by Mesnil, but the smallest mode was only 5-7 cm in U.S. autumn bottom trawl survey samples (Fig. 2).

Individuals from the second cycle first appeared in the May samples at about 10 cm in length. In October this group is represented by a 12-14 cm mode for an average monthly growth of 1 cm through the first year. Mesnil attributed the lower growth rate of late summer spawned individuals to the colder, winter temperatures during their first several months. During their second winter this group matures and is represented as mature individuals with

a mode at 20-28 cm in the May samples.

Many of Mesnil's findings seem to be supported by U.S. research survey and commercial length frequency and maturity data, and further investigation is underway at the Northeast Fisheries Center of the National Marine Fisheries Service to study this proposed life and reproductive cycle. At present an average growth of 1.0-1.5 cm/month is assumed for *L. pealei*, with males growing faster and larger than females (Summers, 1971). The growth function (for males) estimated by Ikeda and Nagasaki[2] is:

$$L = 38.3\,(1 - e^{-0.59t}) \qquad (1)$$

where L = mean mantle length at age t (in years).

Length-weight equations (Lange and Johnson, in press), derived for males and females separately and combined from least squares regression of the $\log_e$ of weight (grams) on $\log_e$ of dorsal mantle length (centimeters) for 1975-77 data are:

Males (n=915)

$$W = 0.41917\,L \cdot \exp 1.97528$$

Females (n=697)

$$W = 0.16762\,L \cdot \exp 2.32364 \qquad (2)$$

Total (n=1,709)

$$W = 0.25662\,L \cdot \exp 2.15182$$

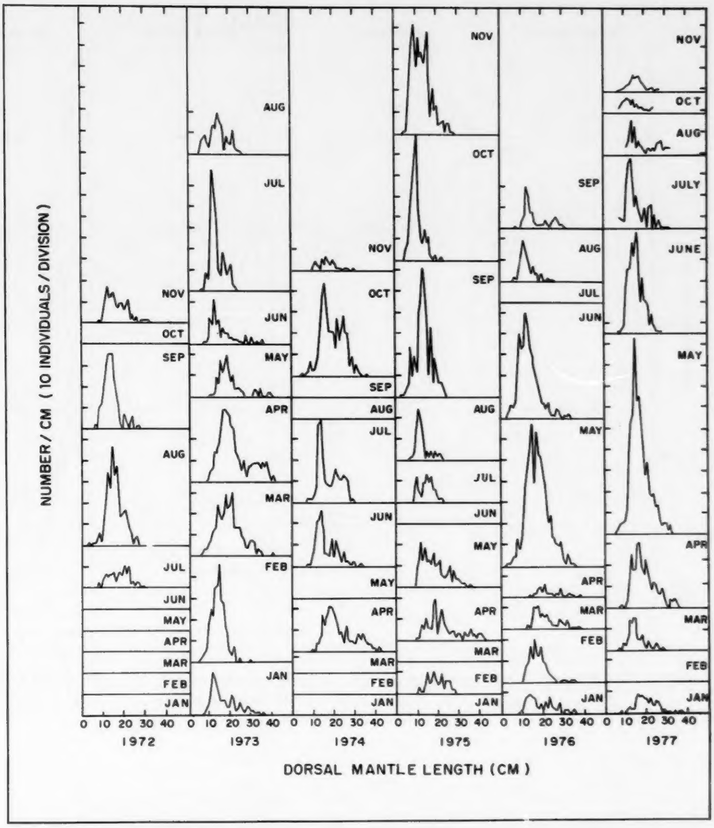


Figure 1.—United States commercial length frequencies for *Loligo pealei* by month, southern New England-Middle Atlantic, 1972-77.

Illex illecebrosus belongs to the oceanic family Ommastrephidae, and little is known of its biology or life history. It is a more northern species than *L. pealei*, ranging to Greenland, but with autumn concentrations as far south as Cape Hatteras (Squires, 1957). Seasonal migrations to coastal Newfoundland, Nova Scotia, and New England, into shallow water (10-50 m) during the warmer months allow for an inshore fishery (Squires, 1957). In late autumn (October-December) movement is to the southeast and open ocean from Newfoundland, and offshore in the area from the Gulf of Maine to Cape Hatteras. Mercer[3] found *I. illecebrosus* in concentrations along the edge of the continental shelf in the summers of 1971 and 1972, in waters with temperatures >5°C. Spawning is believed to occur offshore at great depths from December to June (primarily December to March), with most *I. illecebrosus* dying after spawning (Squires, 1957). However, mature males, which develop sooner than the females, were collected on Georges Bank in August 1963[4] and along the shelf edge in >100 m depths from southern Georges Bank to the waters off Delaware, during a joint United States-Japanese research cruise in July 1977.

Mesnil (1977) has proposed a cross-over life cycle for *I. illecebrosus*, as he has with *L. pealei*. Again, he suggests two overlapping reproductive cycles, with spawning occurring for this

[2]Ikeda, I., and F. Nagasaki. 1975. Stock assessment of *Loligo* in ICNAF Subarea 5 and Statistical Area 6. Int. Comm. Northwest Atl. Fish. Res. Doc. 44, Serial No. 3523, 5 p.

[3]Mercer, M. C. 1973. Distribution and biological characteristics of the ommastrephid squid, *Illex illecebrosus* (LeSueur) on the Grand Banks, St. Pierre Bank, and Nova Scotia Shelf (Subareas 3 and 4) as determined by otter trawl surveys 1970 to 1972. Int. Comm. Northwest Atl. Fish. Res. Doc. 73/79, Serial No. 3031.

[4]R. Wigley, National Marine Fisheries Service, NEFC, Woods Hole, MA 02543, pers. commun. 1975.

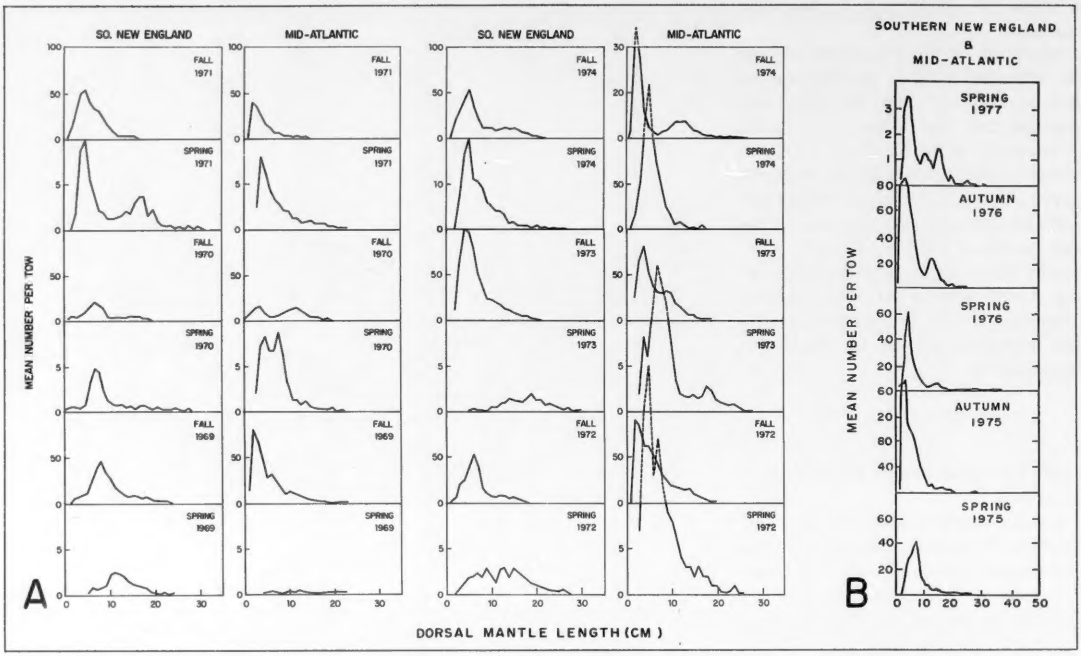


Figure 2.—Mean numbers at length per tow of *Loligo pealei* from U.S. bottom trawl surveys, southern New England and Middle Atlantic. A. Spring 1969 to fall 1974 (Tibbetts, 1977). B. Spring 1975 to spring 1977.

species in January and July, and each generation living about 18 months. So, those individuals which hatched in January-February, would spawn in July of the following year and those hatched in August would spawn in January of their second year. The basis of this proposed cycle is also length-frequency analysis and observations on maturity and growth. Data from six research cruises (from 1973 to 1975) were used in this analysis, and Mesnil found single modes for both sexes in his May and July samples and three modes in each of his September through December samples. He begins by relating a May mode of 14-15 cm to an 18-19 cm July mode, a 21-22 cm September-October mode and a 24-25 cm November to December mode. From this sequence he estimated a 1.6-1.9 cm average monthly growth to calculate that the squid taken in May were 8-9 months old and, therefore, hatched in the previous summer. He then associated this with an 8 cm September mode, and the 11-12 cm November mode, for one complete cycle. Mesnil's second cycle originates with spawning in January by the large individuals of the previous cycle. These first appear in September-October as an 18-19 cm mode, and are represented again in November-December by a 16-17 cm group (sampled from different years) containing many maturing or mature males. Mesnil feels these individuals will spawn during the following July (even though they are not represented in the samples) completing the second cycle. United States commercial length frequencies for *I. illecebrosus* (Fig. 3) generally showed a single mode, progressing from about 17 to 28 cm in length between May and November, though minor modes were also present in some months. These modes generally agreed with Mesnil's observations, but were 1 to 3 cm larger than what he found during each month. United States survey samples revealed large modes of individuals 4-7 cm in length during the spring and autumn of different years (Fig. 4). Though, in general, available data do not refute Mesnil's conclusions, further study of the life cycle of this species is necessary.

It is generally felt that *I. illecebrosus* is fast growing and shorter lived than *L. pealei*, surviving 14-18 months, with monthly growth increments of about 2 cm for both sexes. Squires (1967) stated they attain sizes of up to 33 cm. A growth function for *I. illecebrosus* has been calculated by Au (footnote 1) as follows:

$$L_t = 32.0\,(1 - e^{-0.21t}), \qquad (3)$$

with age t in months (note Equation (3) has been changed to express age in months). This function implies a curve

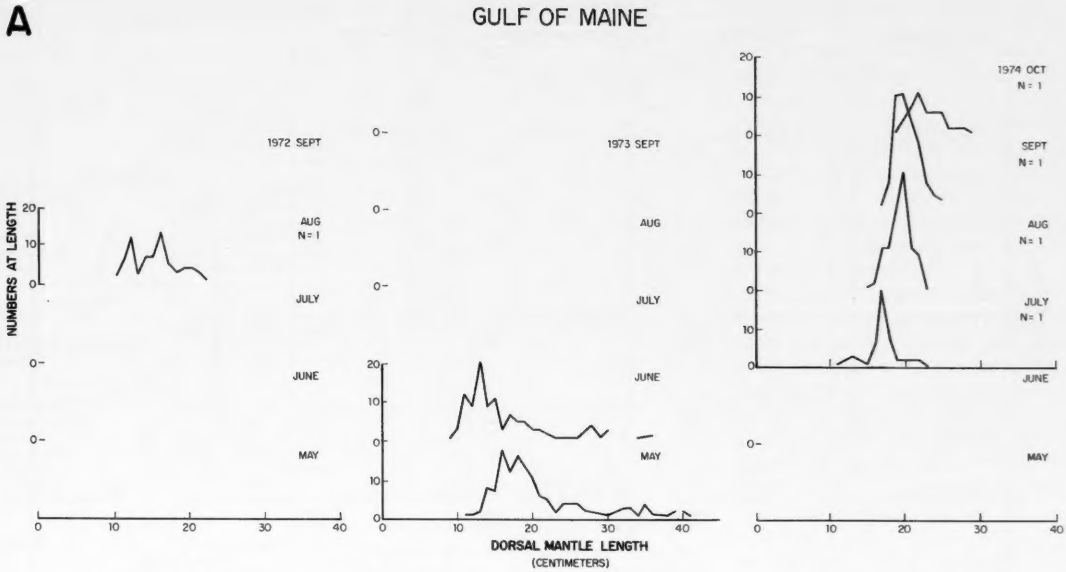
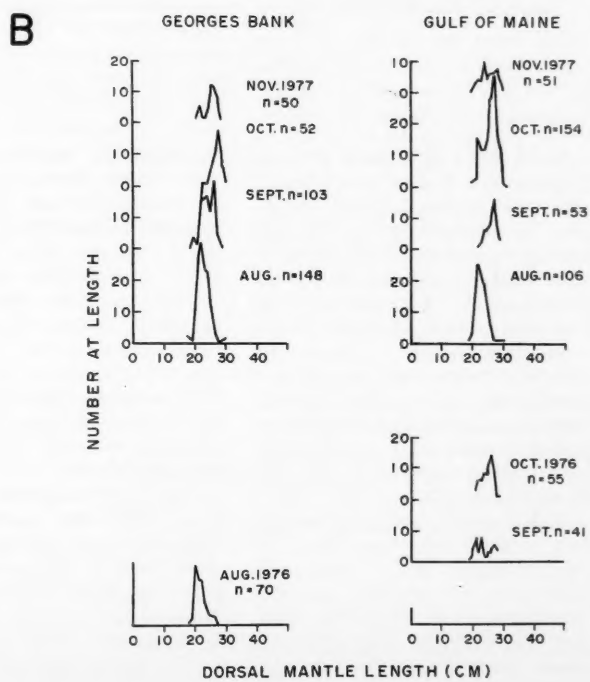


Figure 3.—United States commercial length frequencies for *Illex illecebrosus*, by month, Georges Bank-Gulf of Maine. A. 1972-74, Gulf of Maine. B. 1976-77, Georges Bank and Gulf of Maine.



with length at age $t=0$ at 0 cm, and at age $t=1$ at 6 cm, then growth increments decreasing to 0.6 cm by 15 months. This function does not adequately represent growth in the first few months for this species, since data for that early time period is not available.

The linear least squares fit of $\log_e$ weight (grams) on $\log_e$ dorsal mantle length (centimeters) for *I. illecebrosus*, from 2,605 individuals taken during research vessel cruises in 1975-77 (Lange and Johnson, in press), is:

$$W = 0.04810\,L \cdot \exp 2.71990$$

(n=2,605 including unsexed *I. illecebrosus*) (4)

for males and females, these equations are:

Males: $W = 0.05483\ L \cdot \exp 2.68514$ (n = 1,074) (5)

Females: $W = 0.04397\,L \cdot \exp 2.74348$ (n = 1,511). (6)

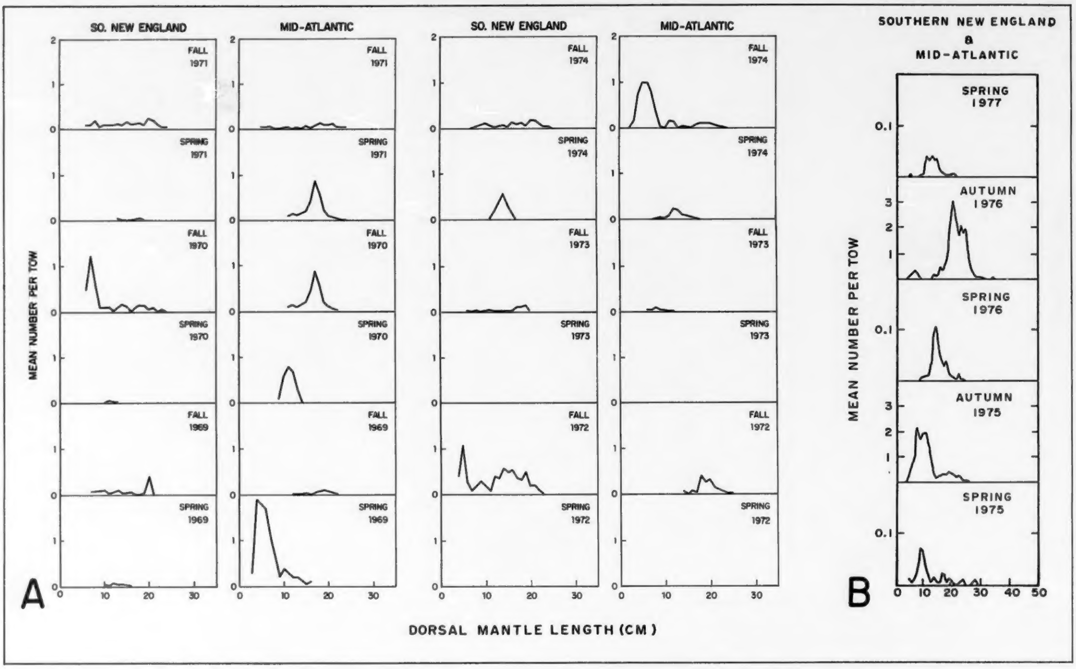


Figure 4.—Mean numbers at length per tow of *Illex illecebrosus* from U.S. bottom trawl surveys, southern New England and Middle Atlantic. A. Spring 1969 to fall 1974. B. Spring 1975 to spring 1977.

Squid play a key role as prey and predator in the flow of energy through the coastal northwest Atlantic ecosystem. They are rapid growing (high production to biomass ratio), abundant, and widely distributed during the warmer months of the year when the ecosystem is more productive. Heavy exploitation of squid could impact other fisheries resources which compete with man for squid as food, while substantial increases in squid abundance might impact on abundance of species of fish that are consumed during early life stages by squid.

Both *L. pealei* and *I. illecebrosus* feed on small fish, crustaceans, and squid (Tibbetts, 1977). Young squid feed heavily on euphausiids and other small crustaceans, but as they grow, their diet gradually changes to small (often young) fish. For example, Squires (1957) reported that as the mantle length of *I. illecebrosus* increased from 10-12 to 25-30 cm, the percentage of individuals with fish in their stomachs increased from 11.8 percent to 62.5 percent. Major prey of *I. illecebrosus* include cod, *Gadus morhua*; haddock, *Melanogrammus aeglefinus*; redfish, *Sebastes marinus*; capelin, *Mallotus villosus*; mailed sculpin, *Triglops nybellini*; Atlantic mackerel, *Scomber scombrus*; Atlantic herring, *Clupea harengus*; and flounders (Squires, 1957; Bigelow and Schroeder, 1953).

Vovk (1972) reported that squid, euphausiids, fish, pandalid shrimp, copepods, crabs, and the above items were found in >25 percent of the *L. pealei* stomachs which he examined. Vovk found a higher occurrence of fish in the stomachs as the squid increased in size. Representatives of various fish groups were found: *Diaphus* (Myctophidae), *Anchova* (Engraulidae), *Stenotomus* (Sparidae), *Clupea* (Clupeidae), and *Alosa* (Clupeidae), with most individual fish between 5 and 19 cm in length.

Squid are the prey of numerous species of fish (Table 2), sea birds, and marine mammals. Mercer[5] discussed the importance of *I. illecebrosus* as a food source of pilot whales, *Globicephala melaena*. Vovk (1972) also reported that squid are an important prey of northern sea birds such as streaked shearwaters and jackass penguins.

[5]Mercer, M. C. 1974. Modified Leslie-DeLury assessments of the Northern Pilot Whale (*Globicephala melaena*) and annual production of the short-finned squid (*Illex illecebrosus*) based upon their interaction at Newfoundland. Int. Comm. Northwest Atl. Fish. Res. Doc. 74/49, Serial No. 3259 (mimeo).

Table 2.—Fish predators of squid (*Loligo pealei* and/or *Illex illecebrosus*) from the northwest Atlantic, Cape Hatteras to Newfoundland.

Pelagic	
bonito	*Sarda sarda*
bluefin tuna	*Thunnus thynnus*
skipjack tuna	*Euthynnus pelamis*
mackerel	*Scomber scombrus*
swordfish	*Xiphias gladius*
Semi-pelagic	
alewife	*Alosa pseudoharengus*
butterfish	*Peprilus triacanthus*
scup	*Stenotomus chrysops*
bluefish	*Pomatomus saltatrix*
striped bass	*Morone saxatilis*
redfish	*Sebastes marinus*
Inshore	
silverside	*Menidia menidia*
smelt	*Osmerus mordax*
three-spine stickleback	*Gasterosteus aculeatus*
weakfish	*Cynoscion regalis*
Other	
spiny dogfish	*Squalus acanthias*
smooth dogfish	*Mustelus canis*
mackerel shark	*Lamna nasus*
thresher shark	*Alopias vulpinus*
barrelfish	*Hyperoglyphe perciformis*
angel shark	*Squatina dumerili*
roughtail stingray	*Pasyatis centroura*
Benthic	
haddock	*Melanogrammus aeglefinus*
cod	*Gadus morhua*
pollock	*Pollachius virens*
red hake	*Urophysis chuss*
silver hake	*Merluccius bilinearis*
spotted hake	*Urophycis regius*
white hake	*Urophycis tenuis*
tom cod	*Microgadus tomcod*
searobin	*Prionotus carolinus*
four-spot flounder	*Paralichthys oblongus*
summer flounder	*Paralichthys dentatus*
windowpane flounder	*Lophopsetta maculata*
witch flounder	*Glyptocephalus cynoglossies*
barndoor skate	*Raja laevis*
little skate	*Raja erinacea*
big skate	*Raja binoculata*
clearnose skate	*Raja eglanteria*
tilefish	*Lopholatilus chamaeleonticeps*
longhorn sculpin	*Myoxocephalus octodecemspinosus*
white perch	*Morone americana*
toadfish	*Opsanus tau*
black seabass	*Centropristis striata*
goosefish	*Lophius americanus*
tautog	*Tautoga onitis*

Maurer[6] found that squid composed over 10 percent of the stomach contents of the bluefish, sea raven, fourspot flounder, spiny dogfish, and goosefish that he examined.

[6]Maurer, R. 1975. A preliminary description of some important feeding relationships. Int. Comm. Northwest Atl. Fish. Res. Doc. 75/IX/130, Serial No. 3681.

Table 3.—U.S. catch (for major New England ports) of *L. pealei*, *I. illecebrosus*, and all squid by month, expressed as percent of the total (1970-76).

	Percentage monthly catch		
Month	*Loligo*	*Illex*	Squid
January	0.7	0.0	2.4
February	1.6	0.0	2.9
March	2.4	0.0	3.4
April	2.4	0.0	4.1
May	57.8	0.0	29.7
June	25.2	5.5	15.2
July	1.8	6.8	5.8
August	0.8	18.3	7.7
September	1.3	27.3	8.0
October	2.9	32.8	10.4
November	2.5	9.0	7.2
December	0.6	0.3	3.3

Commercial Fishery

United States squid catches off New England have been reported since the late 1800's (ranging from 500 to 2,000 t/year), but until recently, there had been no separation of species in reported catches. Interest in squid in the northwest Atlantic by other countries has increased since the U.S.S.R. first reported by-catches in 1964. In 1974 there were nine countries reporting squid catches totaling about 56,000 t (Table 1). Aside from a U.S. trap fishery for *I. illecebrosus* (as bait), squid off the northeast United States are fished with otter trawls. Monthly percentages of U.S. squid catches by species for 1970 to 1976 are given in Table 3.

Japan, Spain, and Italy are the primary participants in the offshore directed squid fishery. Japan began her fishery in 1967, with Spain entering the fishery in 1970 and Italy in 1972 (Table 1). Until 1977, Japan and Italy fished for *L. pealei* from October to March along the edge of the continental shelf. Japan had a butterfish, *Peprilus triacanthus*, fishery associated with its *L. pealei* fishery, occasionally taking more butterfish in a given month, than squid (ICNAF, 1975b, 1976b). Spain, in addition to its winter fishery for long-finned squid, steadily increased its effort in the summer months, exploiting short-finned squid in the same offshore waters. Spain's squid fishery produced substantial by-catch of species such as butterfish and mackerel (up to 65 percent in March and April)[7], most of which was discarded. However, under extended jurisdiction (Fishery Conservation and Management Act (FCMA) of 1976) squid fishing has been restricted in time and locations in an attempt to avoid by-catch, as well as conflicts with domestic offshore lobster gear. A directed fishery for butterfish has not been permitted.

Prior to 1973, when Japan, Spain, Romania, and Bulgaria began reporting squid catches by species, only total squid landings were available; even now not all U.S. landings are reported by species. Recently, however, most nations have supplied ICNAF with estimates of squid catch by species (Table 4), for the years 1965-75. Total squid landings, by species, are presented in Figure 5. Catch composition for 1976 and 1977 is as reported, by species. Those catches which are still reported as squid (nonspecified) have been apportioned to species according to the species composition of the catch of those countries reporting by species.

The catch per day fished with squid (both species) as the main species sought (i.e., either reported as main species or composing >50 percent of the total monthly catches of gear type in an area) for Japan and Spain is given in Table 5. The overall catch per effort (C/E) in the directed offshore squid fisheries of Japan and Spain decreased between 1972 and 1976 in all areas from Georges Bank through the Mid-Atlantic, though C/E of a given vessel class in a given area, may increase in an individual year. Table 6 shows the inshore catch per effort for squid from the U.S. fishery from 1976 through 1978.

United States overall C/E in the inshore fishery had increased from 1973 to 1976 from 1.3 to 5.9 t/day, as a small directed fishery (based on trips where squid composed >50 percent of the catch) developed and consequently

[7]Lopez-Veiga, E. C., and E. Labarta. 1974. Some observations on the Spanish squid (*Illex* and *Loligo*) fishery in Subarea 5 and Statistical Area 6 of the ICNAF. 11 p. ICNAF Working Paper, ICNAF Secretariat, Halifax, N.S.

Table 4.—Squid catches (in tons), by species,[1] year, and country, from the northwest Atlantic, Cape Hatteras to the Gulf of Maine, 1963-78.

Year	Country[2]															Total
	Bulg.	Can.	Cuba	Fra.	FRG	GDR	Ire.	Italy	Japan	Pol.	Rom.	Spain	U.S.A.	U.S.S.R.	Mex.[3]	
								Long-finned squid								
1963													1,294			1,294
1964													576	2		578
1965													709	99		808
1966													722	226		948
1967									5				547	1,125		1,677
1968									177				1,084	2,150		3,411
1969									7,125			438	899	1,080		9,542
1970									13,250			2,790	653	692		17,385
1971	10								10,426			3,446	727	3,560		18,169
1972	20			288	463			2,000	16,293	164	66	5,667	725	4,048		29,734
1973	46			793	1,641			2,360	14,459	911	150	11,148	1,105	5,000		37,613
1974	172	27						3,280	13,493	1,706	3	9,375	2,274	4,520		34,850
1975	34		30		27	16	1,660	3,390	10,748	3,785		7,698	1,621	4,792		33,801
1976	23		257		22	317	1,042	3,304	5,029	1,706	13	9,137	3,602	832		25,284
1977	8	15	28			9		2,237	7,814	232		5,236	1,088	7		16,674
1978								1,366	2,309		17	4,603	1,476	7	1,053	10,831
								Short-finned squid								
1963													810			810
1964													358	2		360
1965													444	78		522
1966													452	118		570
1967									2				707	286		995
1968			10						1,557				678	1,026		3,271
1969			1						586			128	562	260		1,537
1970						20			389			1,636	408	373		2,826
1971	80	1							176			3,324	455	2,578		6,614
1972	479		14	8				1,200	2,398	5,264		4,878	472	2,928		17,641
1973	364			27		313		805	1,067	8,288		3,784	530	3,977		19,155
1974	420							980	3,327	5,003	6	6,769	148	3,975		20,628
1975	171		121			882	3,085	884	3,237	3,051	48	2,204	107	4,136		17,926
1976		54	8		1,101	996	2,241	1,117	3,256	5,050	9	4,063	229	6,812		24,936
1977	52	5	6				23	1,948	4,876	656		8,202	1,024	8,003		24,795
1978								2,131	3,744		50	8,583	385	33	2,769	17,695

[1] 1963-66 estimated breakdown of total squid catch, prorated by ratio of reported *L. pealei* to *I. illecebrosus*, from ICNAF Statistical Bulletins No. 13-16. 1967-76 from ICNAF Sum. Doc. 78/VI/6. 1977 ICNAF Sum. Doc. 78/VI/28. 1978—Preliminary—As reported to NMFS by foreign nations.
[2] Countries are: Bulgaria, Canada, Cuba, France, Federal Republic of Germany, German Democratic Republic, Ireland, Italy, Japan, Poland, Romania, Spain, United States of America, Union of Soviet Socialist Republics, and Mexico.
[3] Mexico did not fish in this area prior to U.S. extended jurisdiction.

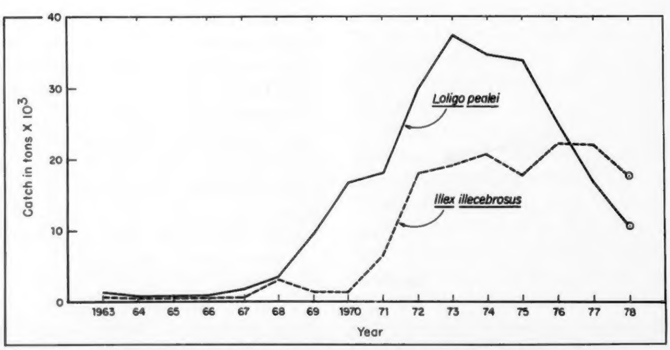


Figure 5.—Total catches of squid, *Loligo pealei* and *Illex illecebrosus*, in metric tons, by species, Cape Hatteras to Gulf of Maine, 1963-78.

more of the squid was landed. However, since 1976, mean C/E of each species has declined, for each vessel size class and in each area. This U.S. directed squid fishery has occurred primarily during a 2-5 week period in the early summer (May-June) when *L. pealei* are inshore in great concentrations to spawn. The vessels involved fish for other species during the remainder of the year and a significant portion of the U.S. squid landings are still as by-catch in other fisheries, although in May 1979 the directed fishery produced about 2,000 t of *L. pealei*. *Illex illecebrosus* is caught by U.S. vessels primarily as by-catch, although during a period of great abundance

Table 5.—Offshore squid landings per day in metric tons by area and gear (for Japan and Spain), 1970-75.

Area	Country	Gear[1] and tonnage class[2]	Year 1970	1971	1972	1973	1974	1975
Georges Bank	Spain	OTSN 4						4.0
	Spain	OTSN 5			14.8	9.2	6.9	3.4
	Spain	OTSN 6						4.4
	Japan[3]	OTSN 5					28.7	21.4
	Japan	OTSN 6	22.6	6.3		16.3	15.0	18.7
	Japan	OTSN 7	37.3	26.3	24.4	33.6	17.9	20.31
South New England	Spain	OTSN 4						3.5
	Spain	OTSN 5		4.0	8.5	7.6	5.5	0
	Japan	OTSN 6	19.7	14.9		14.1		
	Japan	OTSN 7	28.4	11.3	19.9	18.6		
North Mid-Atlantic	Spain	OTSN 4						3.3
	Spain	OTSN 5		7.8	7.9	7.1	7.0	3.8
	Spain	OTSN 6						5.2
	Japan	OTSN 4						25.3
	Japan	OTSN 6	24.3	13.8	18.7	14.4		16.6
	Japan	OTSN 7	32.5	13.4	17.3	13.2		21.25
Central Mid-Atlantic	Spain	OTSN 4						3.4
	Spain	OTSN 5		11.9	12.3		6.9	4.0
	Spain	OTSN 6						5.0
	Japan	OTSN 5						20.2
	Japan	OTSN 6	24.88	12.9		10.0	10.3	10.1
	Japan	OTSN 7	25.3	16.2	17.2	14.4	11.9	14.8
South Mid-Atlantic	Spain	OTSN 4						2.8
	Spain	OTSN 5		8.6	12.9		7.0	4.0
	Spain	OTSN 6						9.0
	Japan	OTSN 5					12.5	17.9
	Japan	OTSN 6				16.4	15.3	15.1
	Japan	OTSN 7			15.4	14.6	16.1	11.7
Total	Spain	OTSN 4						3.5
	Spain	OTSN 5		9.0	11.3	7.4	6.8	3.9
	Spain	OTSN 6						5.3
	Japan	OTSN 5					17.8	20.5
	Japan	OTSN 6	22.8	12.2	18.7	13.4	12.9	14.3
	Japan	OTSN 7	29.9	16.9	18.8	19.7	14.8	16.4

[1]Gear OTSN: Otter trawl stern.
[2]Tonnage class: 4 = 150.00 to 499.9 tons; 5 = 500 to 999 tons; 6 = 1,000 to 1,999 tons; 7 = >2,000 tons.
[3]All Japanese catch/effort based on 24 hours/day.

Table 6.—Inshore catch per effort for squid from U.S. landings per day fished (metric tons) in southern New England and northern Mid-Atlantic, 1967-76.

Year	Metric tons/day	No. of trips
1967	5.6	33
1968	3.4	37
1969	5.4	120
1970	2.2	110
1971	2.6	43
1972	1.8	24
1973	1.3	46
1974	2.2	84
1975	3.2	65
1976	5.9	30

[1]Based on ton class 2 (0-50 tons) vessel trips, with squid composing >50 percent of the catch.

in summer-fall 1976, in the Gulf of Maine, a modest directed fishery developed.

Length Frequency Samples

United States commercial and research survey length samples taken for each species of squid between July 1972 and November 1977 are presented in Figures 1-4.

Modal values for *L. pealei* based on U.S. commercial (inshore) length frequencies (Fig. 1) and U.S. bottom trawl surveys (1969-77; Fig. 2a, b) are generally as would be expected according to the growth and spawning schedules described by Summers (1971), with two or three modes present throughout the year. In the January commercial samples the first mode (11-12 cm) probably represents 7-8 month old individuals, hatched in the previous spring, which will spawn late in the summer. The second and third modes of larger individuals probably hatched late in the summer of 2 years prior (16-18 months). In spring, the larger groups (>18 cm) are mature, and spawning begins with most individuals > 28 cm disappearing from the fishery by summer. *Loligo pealei* of 20-28 cm are present through September, at which time they presumably spawn.

Length samples of *L. pealei* from spring surveys (1969-77; Fig. 3a, b) ranged from 2 to 30 cm, with a major mode generally at 5-8 cm (composing about 70-89 percent of the individuals) and one of lesser importance at 15-30 cm (5-30 percent). From 1974 through 1976 increases in abundance were evident in the first mode, while in 1977 catches of all sizes decreased to the levels of prior years. Autumn frequencies contain fewer large individuals but the overall numbers are increased with recruitment of the 0-group *L. pealei* (3-10 cm). A second mode (13-18 cm) probably represents those individuals hatched late in the previous summer, which did not mature in time for spawning in the current year.

Length frequencies of *L. pealei* from Japanese, U.S.S.R., and Polish commercial catches as reported to ICNAF from 1970 to 1974, are consistent with U.S. samples, demonstrating the presence of larger individuals (30-40 cm) in the fishery in March and April, with the upper limit decreasing to about 19 cm in May. U.S.S.R. 1975 *L. pealei* length frequencies from January through May samples from the southern New England area ranged from 4 to 29 cm. The mean length increased from 12.0 cm in January to 17.3 cm in April and then decreased to 10.2 cm in May. Length samples from the March and April 1975 Polish fishery ranged from 3 to 39 cm with monthly means of 10.5 and 11.9

cm. United States and U.S.S.R. length frequencies from autumn bottom trawl surveys, all strata combined, also exhibit consistent length modes for *L. pealei*.

Monthly length samples of *I. illecebrosus* from the U.S. commercial fishery on Georges Bank (1975-77) and in the Gulf of Maine for 1972-77 (Fig. 4) indicate a single mode through most of the year. In May and June of 1973, however, the distribution was skewed to the right due to the presence of large individuals (23-40 cm) which disappear from the fishery in late summer. As *I. illecebrosus* is believed to spawn from December to June, the great range in length could be due to difference in time of hatching of a single age class. However, as Mesnil (1977) suggested, this could also be the result of two separate spawning groups.

Length compositions from U.S. bottom trawl survey catches of *I. illecebrosus* were also reviewed (Fig. 4). Availability of *I. illecebrosus* in the area during the spring survey is always low, and in 1972 and 1973 there were too few in the samples to obtain length frequency distributions for southern New England and Middle Atlantic strata. For spring samples, there is a single mode (Fig. 5a, b) ranging from 5 cm (in 1969) to 17 cm (in 1971). Autumn samples generally have broader size ranges (4-33 cm) with one or two modes. Combined samples for the southern New England and Middle Atlantic areas give a single mode in 1969 at 20 cm; in 1970-73 there were two modes at 5-7 and 17-18 cm. These modes may represent the two groups of *I. illecebrosus* as described by Mesnil, one spawned early (December-January) and the other late (August-September). The relative strengths of these two modes (when present) varies from year to year. In autumn 1974 and 1975 the first mode (5-10 cm) composed about 70 percent of the total, while in 1976, the second mode (22-26 cm, possibly the same age group) represented about 80 percent of those taken, and in 1977 this second mode (21-28 cm) accounted for 70 percent of the total. However, except when *I. illecebrosus* were in high abundance as in 1976 and 1977, larger individuals were rare in the survey catches. Spring cruises are conducted in late March through April, prior to onshore feeding movements and after many of the larger *I. illecebrosus* have spawned and died. In autumn (late September to mid-November) it is generally assumed that large individuals have begun to move offshore to spawn.

In some cases, modal length increases through time following the growth of a single cohort (note autumn 1975-autumn 1976). The great abundance of large (>20 cm) *I. illecebrosus* in the autumn of 1976 might have been predicted by the strong mode at 5-10 cm in autumn 1975, apparently indicating successful spawning in the summer of that year. Unfortunately, an abundance of larger *I. illecebrosus* did not materialize in the autumn of 1975 following a strong autumn mode at 5-10 cm in the autumn of the previous year.

Length frequencies of *I. illecebrosus*, obtained by the U.S.S.R. surveys, were generally similar to those of the U.S. surveys, with consistent autumn modes at 19-21 cm (from 1969 to 1974). Length samples of *I. illecebrosus* from the U.S.S.R. and Polish fisheries reported to ICNAF[8] (1974-76) show large individuals (26-36 cm) present in the fishery in March, but not in later months. Beginning in May there is a single mode (with an average length of 15 cm); this mean length increases to 23 cm by August, but in September with recruitment of the new age class (5-12 cm) apparently resulting from summer spawning, the overall mean length drops to 17 cm. In October the large *I. illecebrosus* move offshore and the average length in commercial samples drops to 11.5 cm in November.

In general the commercial and research survey length frequencies of both species show the progression of the main group of individuals hatched the previous year. However, in *L. pealei* there may be second and third modes also appearing in the spring, that are variable in importance from year to year. These modes possibly correspond to age-groups two and three. With *I. illecebrosus*, a second mode of small individuals may appear in the autumn, probably as a result of summer hatching.

Length samples from commercial catches generally support Mesnil's hypothesis, with peak spawning periods of spring and late summer for *L. pealei* and winter and summer for *I. illecebrosus*. The relative importance of these spawning periods may vary from year to year and it is not clear that individuals of each species originating from a particular spawning period will, necessarily, spawn during the alternate period, as hypothesized from the cross-over life cycle.

Research Cruise Abundance

Estimates of relative abundance of squid, based on data from U.S. bottom trawl surveys were made for the southern New England-Middle Atlantic (strata 1-12, 61-76), Georges Bank (strata 13-25), and the Gulf of Maine (strata 26-30, 36-40) regions. The location of each strata set is given in Figure 6.

Plots of locations of squid catches made during U.S. bottom trawl survey cruises (Tibbetts, 1977), indicate that both species are distributed across the width of the shelf during autumn surveys, although the extent of onshore distribution of *I. illecebrosus* is variable between years. During spring, *L. pealei* is concentrated along the continental slope (110-200 m) from Cape Hatteras to Georges Bank, and *I. illecebrosus* is found in the survey area only in small numbers (generally from southern Georges Bank, and south). Autumn surveys were consequently chosen as the best measure of relative abundance of these two species in this area (Gulf of Maine to Cape Hatteras). Autumn cruises from 1968 to 1978 were considered as prior to the 1968 cruise. Complete records of the catch of squid, by species, were not kept though it may be noted that fewer squid were taken. The stratified mean catch per

[8]ICNAF Secretariat. 1978. Length composition data for squid-*Illex*, 1973-1976. Int. Comm. Northwest Atl. Fish., Special STACRES (Stand. Comm. Res. Stat.) Meeting Working Paper 78/II/3, 23 p.

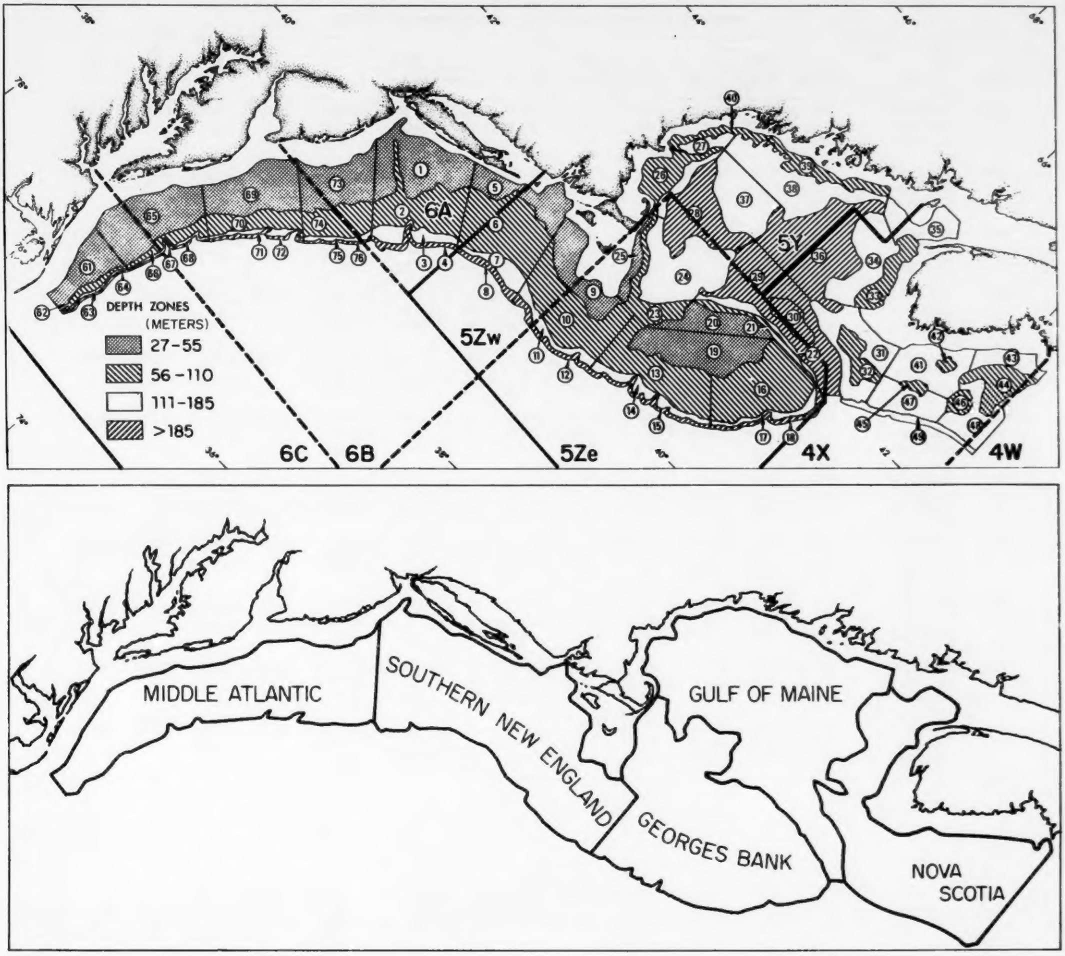


Figure 6.—Strata areas used for relative abundance indices of squid given in Table 5.

tow, in kilograms for both species, was calculated as reported in Table 7 (a and b). *Loligo pealei* is abundant primarily in the southern New England-Middle Atlantic area, and is also consistently found on Georges Bank. In 1975 and 1976, *L. pealei* abundance was significantly higher on Georges Bank than in any year since 1968, while abundance in 1976 and 1977 was slightly less than in 1975 in the southern New England-Middle Atlantic area. The 1978 index from this area was the second lowest since 1968, but may be related as much to late spawning in the summer of 1978 as to a significant reduction in the stock. Spring 1977 and 1978 indices in the southern New England-Middle Atlantic region were also much lower than in recent years (though there is usually great variability in catches during this time of the year). *Illex illecebrosus* catch per tow indices were generally low in all areas, until 1975, when catches in numbers from the southern New England-Middle Atlantic area increased about fivefold over the previous average. Since 1976, *I. illecebrosus* concentrations have been significantly greater than in prior years, especially on Georges Bank and in the southern New England-Middle Atlantic area.

The mean natural logarithm catch per tow (+1) from autumn survey cruises for all areas combined, was used as an

Table 7a.—*Loligo pealei* indices of abundance (stratified mean weight in kg and number per tow by strata set), minimum (B_1) and diel adjusted, minimum (B_2) biomass (in tons) and abundance (in numbers) estimates, 1968-78.

Year	Area	Total No. tows	Total $\overline{Wt.}$/tow	Total No./tow	Day No. tows	Day $\overline{Wt.}$/tow	Day No./tow	Night No. tows	Night $\overline{Wt.}$/tow	Night No./tow	B_1 Wt. t	B_1 No. $\times 10^6$	B_2 Wt. t	B_2 No. $\times 10^6$
1968	SNE/Mid-Atl.	124	10.86	267.57	40	16.23	362.60	43	2.51	30.58	28,073	692.6	29,114	1,211.9
	Geo. Bank	69	0.40	10.73	22	0.77	17.13	25	0.02	0.12				
	Gulf Maine	50	0.01	0.09	18	0.01	0.10	15	0.00	0.11				
1969	SNE/Mid-Atl.	119	13.99	347.50	39	27.32	777.30	39	3.29	51.29	37,643	931.6	48,053	2,393.1
	Geo. Bank	73	1.56	36.70	25	2.49	60.37	32	0.54	9.70				
	Gulf Maine	51	0.03	0.40	17	0.06	0.90	16	0.00	0.00				
1970	SNE/Mid-Atl.	122	4.13	105.40	38	5.55	168.10	40	2.98	63.70	12,095	337.9	19,640	1,946.2
	Geo. Bank	70	1.12	49.40	23	2.99	133.73	24	0.22	6.40				
	Gulf Maine	53	0.05	1.46	18	0.06	1.55	16	0.00	0.00				
1971	SNE/Mid-Atl.	125	4.04	234.20	43	8.55	515.70	41	0.27	11.29	11,752	641.4	14,050	1,106.1
	Geo. Bank	73	1.06	34.10	27	1.51	63.75	24	0.51	9.69				
	Gulf Maine	55	0.03	0.57	16	0.08	1.08	20	0.01	0.42				
1972	SNE/Mid-Atl.	114	9.41	398.90	31	13.14	524.90	40	1.24	31.25	25,400	1,065.1	21,039	1,533.3
	Geo. Bank	73	1.13	39.30	29	1.70	68.71	21	0.28	5.08				
	Gulf Maine	55	0.00	0.20	18	0.00	0.00	18	0.00	0.02				
1973	SNE/Mid.-Atl.	111	14.20	542.90	38	17.47	817.10	35	3.68	66.94	42,338	1,460.9	44,252	3,092.0
	Geo. Bank	73	4.53	60.90	27	7.16	96.15	28	2.31	30.44				
	Gulf Maine	54	0.05	0.91	16	0.08	1.56	21	0.02	0.48				
1974	SNE/Mid.-Atl.	108	11.41	355.90	33	16.33	886.10	38	5.38	130.00	32,014	989.0	46,442	4,757.0
	Geo. Bank	74	2.21	62.07	20	2.67	96.20	26	2.93	22.10				
	Gulf Maine	57	0.03	0.78	19	0.03	0.63	21	0.03	0.23				
1975	SNE/Mid-Atl.	115	15.55	895.50	41	20.27	1,548.40	36	6.11	115.20	41,912	2,412.0	48,636	7,789.0
	Geo. Bank	73	1.80	102.56	23	1.64	142.70	25	0.47	1.82				
	Gulf Maine	65	0.81	0.81	19	0.03	1.56	23	0.02	0.40				
1976	SNE/Mid-Atl.	123	15.79	579.79	37	22.05	979.90	40	3.65	90.74	44,935	1,632.0	51,436	4,372.0
	Geo. Bank	67	3.14	103.52	27	5.82	207.53	19	2.18	54.94				
	Gulf Maine	55	0.36	12.67	14	0.51	16.00	21	1.37	8.58				
1977	SNE/Mid-Atl.	119	11.92	577.89	46	14.20	729.54	35	1.89	94.67	31,600	1,526.0	27,421	3,157.0
	Geo. Bank	101	0.95	43.76	38	1.34	84.06	33	0.23	7.31				
	Gulf Maine	71	0.06	0.81	23	0.04	0.48	22	0.02	0.11				
1978	SNE/Mid-Atl.	134	5.68	196.36	41	8.93	362.00	52	1.37	23.26	16,583	566.0	18,800	1,251.0
	Geo. Bank	156	1.57	45.63	53	4.04	116.10	50	0.41	11.01				
	Gulf Maine	120	0.01	0.18	39	0.06	2.08	45	0.00	0.01				

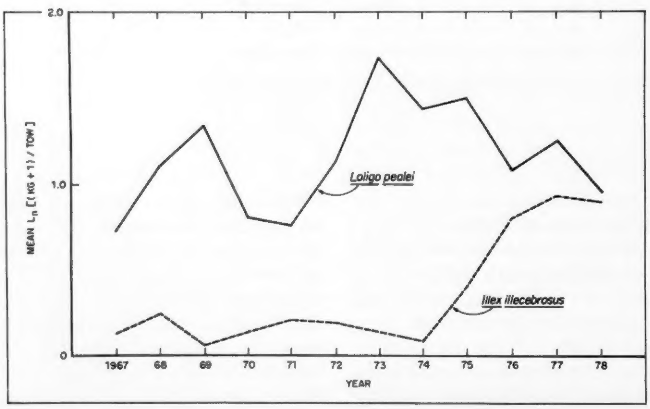


Figure 7.—Squid (*Loligo pealei* and *Illex illecebrosus*) abundance indices for the Middle Atlantic through Georges Bank areas, from U.S. bottom trawl surveys, 1967-78.

index of abundance for each species (Fig. 7) to illustrate the overall trend of squid abundance (1967-78). Log_e mean catch values are used in evaluating squid abundance trends since this transformation tends to adjust the highly skewed distribution of the raw mean catch per tow data. The *L. pealei* index of abundance shows a general increase during the period, 1967-73, while it has been decreasing since then (1974-78). The *I. illecebrosus* index remained at a relatively low, but stable level through 1974, after which it steadily increased from about 20 percent or less of the *L. pealei* index, to a level comparable to that of *L. pealei* in 1978.

Minimum stock size estimates (Table 7) based on U.S. autumn bottom trawl surveys can be obtained from

Table 7b.—*Illex illecebrosus* indices of abundance (stratified mean weight in kg and number, per tow, by strata set), and minimum biomass (in tons) and abundance (in numbers) estimates, 1968-78.

Year	Area	Total			Day			Night			B_1 Wt. t	B_1 No. $\times 10^6$
		No. tows	$\overline{\mathrm{Wt.}}$/tow	No./tow	No. tows	$\overline{\mathrm{Wt.}}$/tow	No./tow	No. tows	$\overline{\mathrm{Wt.}}$/tow	No./tow		
1968	SNE/Mid-Atl.	124	0.48	2.62	40	0.28	1.69	43	0.13	0.60	1,845.4	9.70
	Geo. Bank	69	0.34	1.68	22	0.72	2.35	25	0.04	0.26		
	Gulf Maine	50	0.10	0.46	18	0.18	1.49	15	0.04	0.25		
1969	SNE/Mid-Atl.	119	0.10	0.98	38	0.17	1.64	39	0.06	0.50	418.8	3.60
	Geo. Bank	73	0.04	0.48	25	0.04	0.57	32	0.06	0.43		
	Gulf Maine	51	0.07	0.27	17	0.14	0.51	16	0.00	0.07		
1970	SNE/Mid-Atl.	122	0.29	3.83	38	0.21	4.53	40	0.14	1.54	1,523.6	14.60
	Geo. Bank	70	0.24	2.62	23	0.60	4.89	24	0.05	0.56		
	Gulf Maine	53	0.29	0.82	18	0.50	1.36	16	0.02	0.11		
1971	SNE/Mid-Atl.	125	0.28	1.95	43	0.24	1.94	41	0.13	0.71	2,024.1	10.10
	Geo. Bank	73	0.46	1.70	27	0.55	2.23	24	0.25	0.93		
	Gulf Maine	55	0.43	1.81	16	1.21	4.44	20	0.16	0.85		
1972	SNE/Mid-Atl.	114	0.45	4.86	31	0.42	8.12	40	0.27	1.57	1,716.1	15.00
	Geo-Bank	73	0.20	1.07	29	0.15	0.83	21	0.15	0.72		
	Gulf Maine	55	0.19	0.75	18	0.34	1.50	18	0.04	0.09		
1973	SNE/Mid-Atl.	111	0.07	0.62	38	0.08	0.66	35	0.03	0.30	1,862.0	8.20
	Geo. Bank	73	0.50	2.51	27	0.70	2.51	28	0.44	3.29		
	Gulf Maine	54	0.63	2.02	16	1.57	5.19	21	0.09	0.26		
1974	SNE/Mid-Atl.	108	0.18	4.07	33	0.11	7.98	38	0.20	1.23	2,500.0	18.02
	Geo. Bank	74	0.16	1.12	20	0.22	1.19	26	0.09	0.58		
	Gulf Maine	57	1.16	3.92	19	1.76	5.88	21	0.46	1.41		
1975	SNE/Mid-Atl.	115	0.99	15.74	41	1.11	23.08	36	0.23	1.58	8,306.0	60.25
	Geo. Bank	73	1.11	6.41	23	1.85	13.01	25	0.76	2.03		
	Gulf Maine	65	2.71	7.31	19	3.34	9.17	23	0.29	0.60		
1976	SNE/Mid-Atl.	123	6.23	19.79	37	2.60	11.23	40	3.90	10.49	42,929.0	134.34
	Geo. Bank	67	14.78	45.03	27	8.06	23.83	19	3.54	9.82		
	Gulf Maine	55	4.20	13.75	14	5.25	16.83	21	1.35	3.47		
1977	SNE/Mid-Atl.	119	4.46	15.79	46	3.93	16.21	35	2.32	7.71	21,747.0	73.34
	Geo. Bank	101	5.02	15.81	38	4.09	15.23	33	5.31	16.23		
	Gulf Maine	71	2.21	7.24	23	4.26	14.82	22	0.40	1.29		
1978	SNE/Mid-Atl.	134	2.57	19.50	41	2.53	24.66	52	1.97	8.54	26,435.0	120.68
	Geo. Bank	156	12.17	44.67	53	34.25	109.75	50	2.68	12.56		
	Gulf Maine	120	1.91	5.84	39	3.75	11.25	45	0.41	1.41		

areal expansion of the stratified mean weight or number per tow for each species. A first approximation of this stock size, B_1, was made using the equation:

$$B_1 = \frac{WA}{a} \tag{7}$$

where B_1 = estimate of biomass or abundance, W = stratified mean weight or number per tow, A = strata area sampled (in square miles), and a = area swept by each tow (0.011 miles^2).

Diel variations (caused by vertical migrations) in relative apparent abundance of *L. pealei* are significant, with daytime (0800 to 1600 hours) survey catches 2.66 and 18.77 times greater (in weight and number, respectively), than nighttime catches (2000-0400 hours) according to Sissenwine and Bowman (1978). Therefore, a second estimate (B_2) of *L. pealei* abundance was made by adjusting night catches upward when calculating stratified mean catch per tow, prior to areal expansion (Table 7a). As diel variations in *I. illecebrosus* were not found to be significant, no adjustment was made to the initial biomass estimate (B_1) for that species (Table 7b).

It should be noted that the spatial distribution of *I. illecebrosus* is broader than the area covered by the U.S. bottom trawl surveys. This species is also abundant north and east of the survey area (along the coast of Canada) and the abundance of *I. illecebrosus* further offshore is unknown. Consequently, the abundance indices observed in the survey areas may reflect yearly distributional differences in these areas for this species, and not overall population size. The biomass estimate for *I. illecebrosus* (B_1) from 1968 to 1975 averaged only 7.5 percent of the *L. pealei* estimates in weight, while since then (1976-78) they have increased to 97.8 percent of the *L. pealei* value. However, a much greater difference exists in population size in numbers. Estimated numbers of *L. pealei* in 1976 ($4{,}372 \times 10^6$) were 33 times that of *I. illecebrosus* (134.3×10^6), while biomass estimates differed only by a factor of 1.2 (51,436 vs. 41,929, respectively). In 1977 and 1978, *I. illecebrosus* biomass estimates remained high while *L. pealei* decreased; and the 1978 catch

of *I. illecebrosus* was 40 percent greater (26,435 vs. 18,800 t) than that of *L. pealei*, while in terms of numbers, it was 90 percent less.

Biomass estimates for *I. illecebrosus* have also been made by the U.S.S.R. for the area of Georges Bank and Nova Scotia. These estimates made from areal expansion of survey catches, were: 100,000 t in 1971; 58,000 t in 1972; 197,000 t in 1975, and 258,000 t in 1976 (Konstantinov and Noskov[9]).

Loligo pealei and *Illex illecebrosus* in commercial length samples are usually >8 and 10 cm in mantle length, respectively. Therefore, the abundance of individuals less than or equal to the appropriate length at recruitment, in autumn bottom trawl survey catches, may be a useful prerecruit index (Table 8).

For *L. pealei*, most of the catch in numbers during the autumn surveys are prerecruits, but these are much less important to survey catch in weight. Even though these *L. pealei* prerecruits are the mainstay of the winter offshore fishery there has been no significant correlation between these indices and subsequent catches or C/E in the commercial fishery, or in subsequent survey catches.

Illex illecebrosus prerecruits are rare in the survey catches, but when they are abundant, as a result of significant summer spawning, they may be a good predictor of the following summer's fishery (note 1975-76). This relationship, however, needs further verification. It should also be noted that when *I. illecebrosus* prerecruits are scarce, the abundance during the following summer may still be high as a result of successful winter spawning.

Table 8.—Pre-recruit indices of squid. (Stratified mean number per tow of *L. pealei* and *I. illecebrosus* of all sizes and of *L. pealei* ≤8 cm and *I. illecebrosus* ≤10 cm mantle length in autumn bottom trawl survey, Middle Atlantic to Georges Bank.)

	Loligo (#/tow)		*Illex* (#/tow)	
Year	All sizes	≤ 8 cm	All sizes	≤ 10 cm
1967	134.5	126.9	2.1	0.7
1968	176.5	159.9	2.3	0.6
1969	237.3	217.4	0.8	0.3
1970	85.6	79.3	3.4	0.2
1971	163.3	161.5	1.9	0.6
1972	271.4	258.5	3.5	1.8
1973	372.0	353.9	1.3	0.3
1974	251.7	233.3	3.0	2.1
1975	614.4	593.3	12.4	9.6
1976	410.9	302.5	28.7	0.6
1977	388.5	297.7	15.8	1.1
1978	144.2	93.4	28.4	5.1

Simulation Model of Squid Populations

The traditional stock assessment methods which are usually applied to finfish species are not readily applicable to squid populations. Surplus-production or stock-production models (such as the Schaefer model) are not applicable because of the short time series of catch and effort data. Virtual population analysis as presented by Ikeda and Nagasaki (footnote 2), requires estimates of the age-class structure of the catch which are presently unavailable. Au (footnote 1) applied the Beverton and Holt yield per recruit equation (dynamic pool model) to both species of squid, but this model has several shortcomings in this case. The Beverton and Holt model assumes that fishing and natural mortality ratios are constant during the exploited phase of the life cycle and these assumptions are too restrictive for squid.

Therefore, a dynamic pool model designed specifically to simulate the effect of fishing on squid was developed (Sissenwine and Tibbetts, 1977). The model allows monthly values of instantaneous growth, fishing, and natural mortality rates. A 1-year life cycle with winter (January-March) spawning and a 2-year life cycle with summer (May-September) spawning were assumed for *I. illecebrosus* and *L. pealei*, respectively. The model also simulated postspawning mortality.

A major shortcoming of fisheries management based on yield per recruit (YPR) considerations is that fishing at F_{max} (which maximizes YPR) usually results in a severe reduction in spawning stock biomass and increases the probability of recruitment failure. The fishing mortality rate where the increased yield of an additional unit of effort is 10 percent of the yield from the first unit of effort ($F_{0.1}$) is often selected as a target fishing mortality in order to lessen the reduction in spawning stock biomass and thus guard against recruitment failure. An alternative approach was applied in the simulation model described here. The relationship between spawning stock size and recruitment to the exploited phase of the next generation was assumed as follows:

$$R = \frac{P}{1 + A(P-1)} \qquad (8)$$

(Beverton and Holt, 1957) where R and P are the number of recruits and weight of spawners, respectively, related to the unexploited stock, i.e., R and P both equal 1.0 for the unexploited stock. A is a parameter ranging from 0 to 1.0. The function is graphed in Figure 8 for the three values of A (0.4, 0.8, and 1.0) applied to squid. In order to calculate the maximum sustainable yield per recruit and corresponding exploitation rate (E_{MSY}), the model was run for successive generations until recruitment converged to an equilibrium value. Because of uncertainty in the life cycle and parameter estimates used in the models for *L. pealei*, and particularly *I. illecebrosus*, simulation results should be applied with caution. Nevertheless, in the absence of more definitive results, the simulations do offer some guidance in selecting a target exploitation rate. As expected, the simulation results were most sensitive to the input value of A. Typical results for the equilibrium YPR and the mean weight of individuals in the catch corresponding to an exploitation rate of E_{MSY} for A equal 0.4, 0.8, and 1.0 are given in Table 9. E_{MSY}, corresponding to a moderate stock-recruitment relationship (A = 0.8), was selected as a target exploitation rate in order to determine the annual catch limit (TAC under ICNAF, optimum yield under FCMA) for *L. pealei* in 1977. The same catch limit has been maintained to date. The choice of $A = 0.8$ is arbitrary, but this value is

[9]Konstantinov, K. G., and A. S. Noskov. 1977. Report of the USSR investigations in the ICNAF area, 1976. Annu. Rep. Int. Comm. Northwest Atl. Fish. 1976, Summ. Doc. 77/VI/15.

Table 9.—Yield per recruit (YPR) and mean weight of individuals in the catch (*W*) of squid by species, corresponding to the exploitation rate that maximizes sustainable yield (E_{MSY}) for a strong (A = 0.4), moderate (A = 0.8), and no stock recruitment relationship (A = 1.0).

Species	Stock-recruitment relationship	*Y* (g)	*W* (g)	E_{MSY}
L. pealei	None	39	52	0.75
	Moderate	29	72	0.40
	Strong	13	85	0.15
I. illecebrosus	None	45	72	0.63
	Moderate	33	90	0.37
	Strong	15	100	0.15

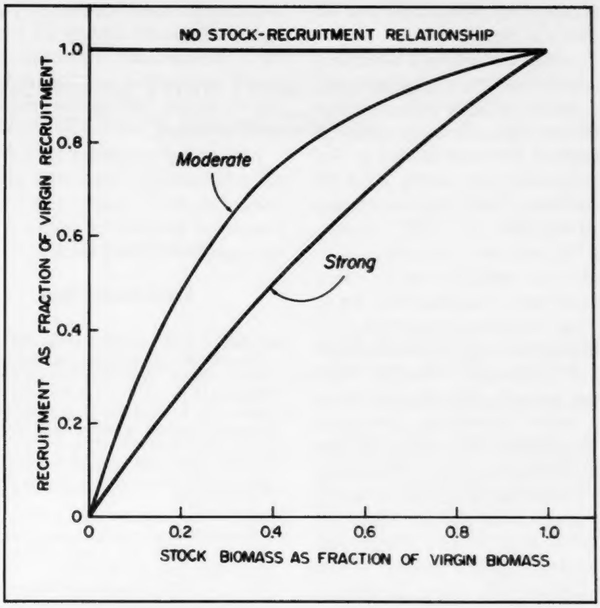


Figure 8.—Relationship of recruitment (R) to spawner biomass (P) of the form $R = P/[1 + A(P-1)]$ for values of A applied to squid.

more reasonable than the other examples of A considered in the analysis. If $A = 1.0$, then E_{MSY} corresponds to fishing at F_{max} and past experience with finfish indicates that fishing at this level of mortality results in recruitment overfishing. Unless stock size has been grossly underestimated, if $A = 0.4$, the stock should have already shown signs of overfishing, but this is not the case.

Population size estimates of *L. pealei* range from about 1 to 7 billion individuals between 1968 and 1977. These are probably underestimates since they are based on the areal expansion of bottom trawl survey data (see Sissenwine[10]). Most of the squid taken in autumn bottom trawl surveys were small recruiting squid. Therefore, an annual recruitment of >1.5 billion *L. pealei* seems likely. If a moderately strong stock recruitment relationship (A = 0.8) is assumed, then a catch of about 44,000 t ($1.5\times10^9 \cdot 0.40 \cdot 72\times10^{-6}$ t) is indicated by the model.

The biomass of *I. illecebrosus* on Georges Bank and the southern Scotian Shelf was estimated by areal expansion as 100, 58, 197, and 258 thousand tons during the summers of 1971, 1972, 1975, and 1976, respectively (Konstantinov and Noskov footnote 9). The high abundance of *I. illecebrosus* in 1976 was confirmed by Canadian, French, Polish, and United States research vessels. Applying E_{MSY} = 0.37 (for a moderate stock-recruitment relationship), these estimates indicate a catch of 37, 21, 73, and 95 thousand tons during the appropriate years according to the model. This stock supports fisheries in both Canadian and United States fishery zones. A total northwest Atlantic catch of *I. illecebrosus* of 55,000 t was recommended for 1976 and again for 1977 by the Standing Committee on Research and Statistics (STACRES) of ICNAF with 25,000 t and 30,000 t to be allocated to Canadian and United States waters, respectively. The regulations that were established were more liberal than STACRES' recommendations (particularly in Canadian waters) with a resulting total catch of 69,500 t in 1976, about 105,000 t in 1977, and about 117,000 t in 1978. If the U.S.S.R. biomass estimates are realistic, then even a catch of 55,000 t would result in an exploitation higher than E_{MSY} in some years according to the model (for A = 0.8).

Discussion and Conclusions

Management of squid stocks (*L. pealei* and *I. illecebrosus*) in the northwest Atlantic began in 1974 with establishment, by ICNAF, of a preemptive quota of 71,000 t, based on early estimates of *L. pealei* stock size. As more information relative to the biology of the populations of *I. illecebrosus* and *L. pealei* became available, a model simulating the effect of fishing on these stocks was developed (Sissenwine and Tibbetts, 1977). This model incorporates relevant biological information and assumptions on growth, spawning, recruitment, and mortality, with knowledge of the fishery based on historical monthly catch statistics, and estimates of population size from research vessel surveys, to determine the maximum sustainable yield per recruit

[10]Sissenwine, M. P. 1976. A review of stock size estimates of squid (*Loligo* and *Illex*) in Subarea 5 and Statistical Area 6. Int. Comm. Northwest Atl. Fish. Res. Doc. 76/VI/31, Serial No. 3811, 4 p.

and corresponding exploitation rate for each species of squid.

For *L. pealei*, assuming a moderately strong stock recruitment relationship ($A = 0.8$), models indicate an exploitation rate of 0.40, with an average weight of individuals in the catch of 72.4 g. Annual recruitment is probably >1.5 billion individuals, indicating that a yearly catch of 44,000 t ($1.5 \times 10^9 \cdot 0.40 \cdot 72 \times 10^{-6}$ t), may be reasonable.

Stock size estimates for *I. illecebrosus* are more variable than for *L. pealei*, and since this species ranges to areas beyond the scope of research surveys and commercial fisheries, these estimates may not reflect the abundance of the entire population. However, these do provide information for preliminary estimates of appropriate catch levels. Assuming a moderate stock-recruitment relationship, with an exploitation rate of 0.37, these estimates indicate catches between 21,000 and 95,000 t may have been appropriate during recent years. Unless available stock size estimates are below actual values, however, recent levels of catch may produce exploitation rates in some years which are greater than E_{MSY}, according to the model.

Recent decreases in catch and catch per effort in the directed squid fishery, especially for *L. pealei*, may indicate lower abundance of these stocks due to declines in recruitment. As suggested by the model, when $A = 0.8$, at E_{MSY} recruitment should decrease by 28 percent for *L. pealei* and by 25.5 percent for *I. illecebrosus*. However, the apparent declines in recruitment may be due to natural fluctuations and not related to fishing.

Further understanding of the biological relationships, especially stock recruitment, of *L. pealei* and *I. illecebrosus* is needed for more rational management of their stocks.

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Squid Catches Resulting From Trawl Surveys off the Southeastern United States

J. DAVID WHITAKER

Introduction

The importance of the squid fishery off the northeastern United States has grown considerably since 1964 with recent squid catches by foreign fleets averaging 50,000 t (110,231,000 pounds) annually (Rathjen et al., 1977). Due to rising value of this fishery and increased interest in expanding the domestic fishery, underexploited squid stocks south of Cape Hatteras and in the Gulf of Mexico are being more closely examined.

However, few studies have examined the distribution and abundance of squids common to these areas. Whitaker (1978) examined several aspects of the biology of *Loligo pealei* and *L. plei*, and Wenner et al. (1979a, 1979b) briefly discussed cephalopod catches from otter trawl surveys in the South Atlantic Bight.

Four species are common in the continental shelf waters off the southeastern United States. Three species, *Loligo pealei, L. plei* and *Lolliguncula brevis* belong to the family Loliginidae. *Loligo pealei*, the long-finned squid, is intensively fished by foreign vessels between Georges Bank and Cape Hatteras (Kolator and Long, 1979) and is the most widely distributed loliginid in the western Atlantic (Cohen, 1976). Seasonal distribution off New England as related to water temperature has been examined by Summers (1969), Vovk (1969) and Serchuk and Rathjen (1974). Information of this type is limited for populations south of Cape Hatteras (Whitaker, 1978).

Loligo plei, the arrow squid, rarely occurs north of Cape Hatteras and current commercial catches off the southeastern United States are not substantial. *Lolliguncula brevis*, the brief squid, is coastal and is often taken in estuaries. Its known range is from Maryland to Rio de la Plata (Voss, 1956). Incidental catches in the shrimp trawl fishery constitute most of South Carolina's squid landings (4,600 kg or 10,120 pounds in 1978) and are sold locally as bait[1].

Illex illecebrosus, the short-finned squid, is also common off the southeastern United States. This species, which supports a large fishery in Canada, has been collected from the continental shelf north of Cape Hatteras during fall but is restricted to the shelf edge during spring (Rathjen, 1973). Roper et al (1969) reported it from deeper waters south of Cape Hatteras. Although this species grows to relatively large size, it is considered inferior in taste and texture to *L. pealei* which reduces its price on the foreign market (Kolator and Long, 1979).

The surveys conducted in the Atlantic Ocean off the southeastern United States since 1973 have provided the first comprehensive trawl data for squid in these waters. In this paper I present some observations on distribution and abundance of *Loligo* and *Illex*.

Materials and Methods

Squid data came primarily from groundfish cruises of the Marine Resources Monitoring, Assessment, and Prediction (MARMAP) program[2]. Specimens were collected during 1973-77 with all seasons represented by at least one cruise. Stations from Cape Fear, N.C., to Cape Canaveral, Fla., were selected using a stratified random sampling design with a set number of stations in each of six depth zones: 9-18 m (29.5-59 feet), 19-27 m (62.3-88.6 feet), 28-55 m (91.8-180.4 feet), 56-110 m (183.7-360.8 feet), 111-183 m (364-600.2 feet), and 184-367 m (603.5-1,203.8 feet). All samples were collected using a ¾-scale version of a Yankee No. 36 trawl with a 16.5-m (54.1-foot) footrope, 11.9-m (39-foot) headrope, and a 1.3-cm (0.5-inch) stretch-mesh cod end liner. Although this net is not designed for efficient squid capture, it does collect enough specimens for relative abundance and distribution analysis. Trawl tows were 0.5 hour long and made during daylight and darkness.

Additional data were obtained by MARMAP personnel during an exploratory cruise aboard the Spanish FV *Pescapuerta Segundo* from 31 May to 15 June 1978. Trawls were made on the continental slope from lat. 38.5° to

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[1]Theiling, Dale. Statistics Section, South Carolina Wildlife and Marine Resources Department, P.O. Box 12559, Charleston, SC 29412. Pers. commun.

[2]Sponsored by the National Marine Fisheries Service under contract 6-35147.

Table 1.—Percent occurrence of *Loligo* in different seasons and depth zones. Parentheses enclose the total trawls per season per depth zone. Means represent percent occurrence in all trawls pooled by season or depth zone.

Depth (m)	Spring	Summer	Fall	Winter	$\bar{x}$
9-18	79(28)	85(48)	83(18)	60(50)	75
19-27	79(24)	68(50)	94(18)	87(45)	80
28-55	86(35)	64(66)	84(19)	90(59)	79
56-110	79(28)	63(41)	79(14)	71(41)	71
111-183	71(21)	93(29)	100(10)	81(21)	85
184-367	30(20)	28(29)	62(8)	39(23)	35
$\bar{x}$	73	68	85	74	

Table 2.—Catch rates >10 kg/tow of *Loligo*, 1973-77.

Depth (m)	kg/tow	Bottom temp. (°C)	Date
22	13.6	25.7	Aug. 1974
59	12.2	21.8	Sept. 1976
68	13.9	19.1	Jan. 1976
75	11.4	25.6	Nov. 1973
155	10.4	12.8	Aug. 1974
155	10.9	13.5	Aug. 1974
155	18.1	16.8	Nov. 1973
157	11.2	13.5	Feb. 1976
172	24.3	14.1	Aug. 1975
174	17.2	27.3	Nov. 1973
179	36.6	10.0	Aug. 1976
194	27.7	14.2	Nov. 1973
198	41.7	13.1	Aug. 1975

30.2°N at depths ranging from 99 to 375 m (from 324.7 to 1,230 feet). The net used most often during this cruise was a bottom trawl with a 78-m (255.8-foot) headrope and numerous steel floats.

All squid were counted, weighed, and measured (mantle length to the nearest centimeter). Larger samples were often representatively subsampled. Hydrographic data were recorded at each trawl station. Data for *L. pealei* and *L. plei* were combined due to questionable identification of specimens from several samples and to facilitate biomass and distribution analysis. Since preliminary analysis showed little north-south variation between catches, I made no latitudinal distinction. Data from all years are combined for analysis of seasonal effects.

Results and Discussion

Loligo were present at 543 (73 percent) of the 745 bottom trawl stations occupied from 1973 to 1977. Frequency of occurrence appeared to be uniform during all seasons and in all depth zones, except at the 184-367 m (603.5-1,203.8 foot) zone where squids were consistently less common (Table 1). Squid appeared to move to the deeper continental slope waters during summer and fall when water temperatures on the shelf exceeded 20° C (Fig. 1). Catch per effort (kg/tow) in the 9-18 m (29.5-59 foot) zone was greatest during the warmer months.

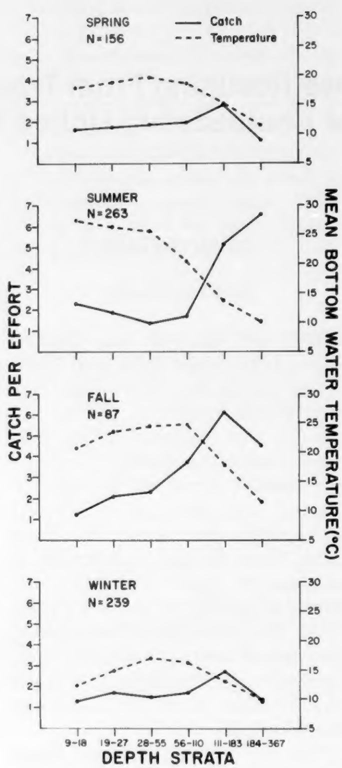

Figure 1.—Mean catch per effort (kg/tow) compared with bottom water temperature for all seasons and depth strata. Catch per effort was estimated for each depth stratum following the methodology of Bliss (1967) and Wenner et al. (1979a).

Catches were more uniform across the shelf during winter and spring which indicates dispersal and a possible movement towards shallower water, perhaps in response to reduced temperatures. Only 13 samples contained a catch biomass >10 kg (>22 pounds); 12 of these stations were in waters >50 m (>164 feet) and nine occurred at depths >150 m (492 feet) (Table 2). From a total of 96.7 kg (212.7 pounds) of *Loligo* taken in the 184-367 m (603.5-1,203.8 foot) zone, 18.4 kg (40.5 pounds) (19 percent) were taken at ≥200 m (≥656 feet) and only 4.4 kg (9.7 pounds) (4 percent) were taken at ≥250 m (≥820 feet).

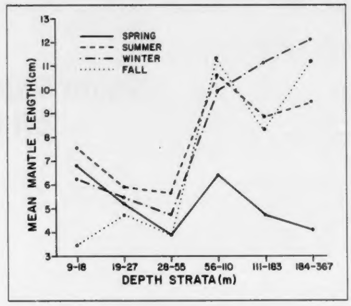

Figure 2.—Mean mantle lengths of *Loligo* by season and depth. Each point is the mean of at least 98 specimens.

Larger-sized *Loligo* were located offshore during all seasons except spring (Fig. 2). The greatest change in mean mantle length with depth occurred during fall when squid in the 9-18 m (29.5-59 foot) zone were much smaller ($\bar{x}$ = 3.5 cm or 1.4 inches) than those collected during the other seasons ($\bar{x}$ = 6.2-7.6 cm or 2.4-3 inches). Mean values are somewhat misleading, however, because size ranges were very large and length-frequency modes were often less than the means. Modes were ≤5 cm (≤2 inches) in 18 of 24 observations (four seasons at six depth zones). Small squid (≤5 cm or 2 inches) were absent only in the 184-367 m (603.5-1,203.8 foot) zone during summer, fall, and winter.

Catch per effort in relation to bottom temperature also showed seasonal differences (Fig. 3). Although bottom

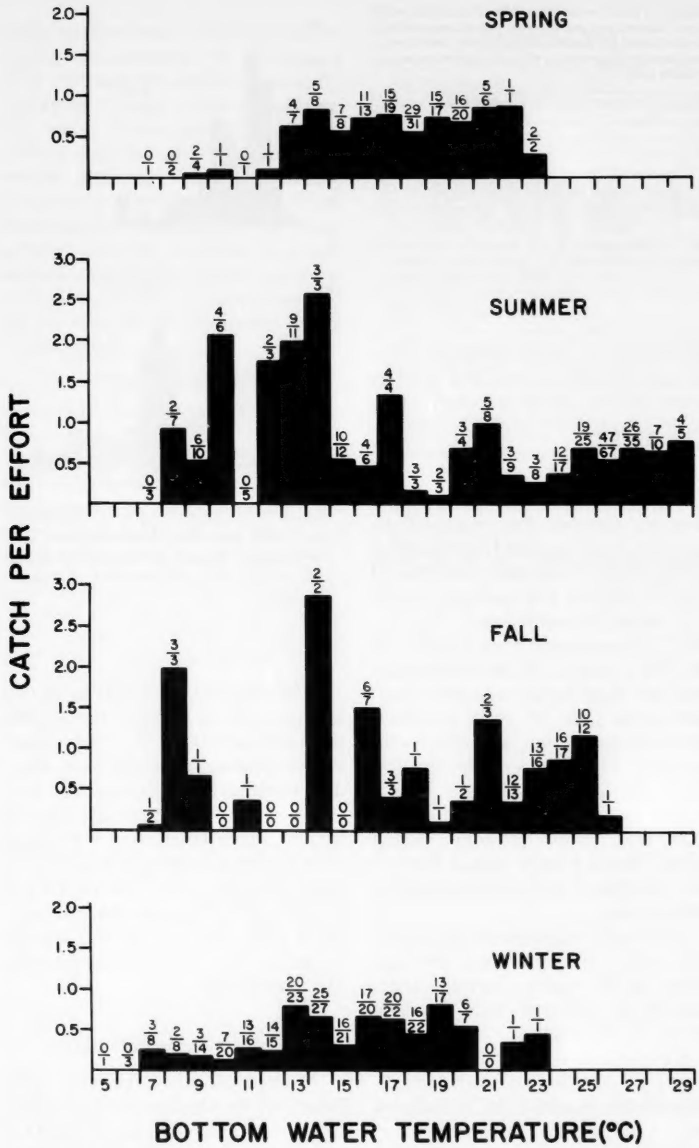

Figure 3.—Catch per effort of *Loligo* as ln(x + 1) where x is mean catch (kg) per tow for stations at each temperature degree. Each fraction shows the total number of stations with *Loligo* over the total number of stations at that temperature and season.

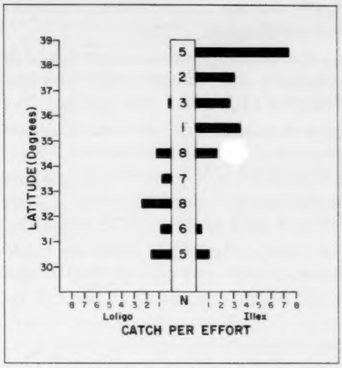

Figure 4.—Catch rates (kg/h) from the Spanish FV *Pescapuerta Segundo*, 31 May-15 June 1978. Data are shown as ln (x + 1) where x is the mean catch rate per degree of latitude. N is the number of trawls per degree of latitude.

temperatures where *Loligo* were taken ranged from 7° to 29°C, the greatest catch per effort was observed during summer and fall at stations with temperatures of 10°-14°C. Some *Loligo* were always present in the warmest temperatures available. During spring and winter, squid were more uniformly distributed with regard to temperature.

Trawls by the FV *Pescapuerta Segundo* did not find any substantial quantities of *Loligo* both north and south of Cape Hatteras (Fig. 4). Catches ranged from 0 to 33 kg (0 to 72.6 pounds) per hour.

Some of the inconsistencies in the above MARMAP data can be explained when *L. pealei* and *L. plei* are considered separately. Whitaker (1978) observed that temperature was the most important factor determining seasonal distributions. *Loligo pealei* appears to prefer cooler temperatures (7°-22°C) remaining on the continental slope during summer and fall and then migrating to the continental shelf in winter and spring. These seasonal distribution patterns are different from those of *L. pealei* off New England where squid are found in shallow waters during the warmer seasons (Summers, 1969; Vovk, 1969; Serchuk and Rathjen, 1974). *Loligo plei*, on the other hand, prefers warmer temperatures and usually remains in waters <50 m (<164 feet) deep. Larger *L. plei* apparently migrate

south with the seasonal drop in temperature (Whitaker, 1978).

Illex illecebrosus was often found in relatively deep water south of Cape Hatteras (Table 3). This species was present at less than 1 percent of all stations shallower than 56 m (183.7 feet) but occurred at 50 percent of all stations in the 184-367 m (603.5-1,203.8 foot) zone. A total of 78 kg (171.6 pounds) was collected in 40 of 80 trawls made between 184 and 367 m (603.5 and 1,203.8 feet) composing 89 percent (by weight) of all short-finned squid taken. In the deeper zone, 59 percent (52 kg or 114.4 pounds) were taken between 250 and 300 m (820 and 984 feet). Only 4 percent (3.6 kg or 7.9 pounds) were captured between 300 and 367 m (984 and 1,203.8 feet).

Illex illecebrosus catches were less than 2.7 kg (5.9 pounds) at each of the 68 stations where this species occurred except for a 25.4-kg (55.9-pound) catch made during summer 1974 at 293 m (961 feet). Seasonal differences in catch per effort were minimal but a single large catch in January 1978 (not included in the analysis) is worthy of mention. This catch, taken east of the Georgia-Florida border at 223 m (731.4 feet), consisted of 4,100 squid weighing 713 kg (1,568.6 pounds) and was 28 times larger than any previous *I. illecebrosus* catch. These squid were large, having a modal length of 22 cm (8.6 inches) and a 20-27 cm (7.8-10.5 inch) size range.

Illex illecebrosus prefers relatively cold continental shelf water. Water temperatures where this species was collected ranged from 7.3° to 27.3°C but only 3.5 percent (by weight) of the total catch were taken in water ≥15°C. Mean temperatures for the 184-367 m (603.5-1,203.8 foot) zone ranged from 9.8°C in winter to 11.2°C in spring. Of all *I. illecebrosus* collected, 79 percent were taken in 8°-10°C water. Squires (1957) jigged short-finned squid near Newfoundland when the surface temperature range was 8.9°-14.4°C. However, he found squid on the Grand Banks where bottom temperatures were 0.5°-8.0°C.

The limited data available indicate that *I. illecebrosus* size increases with depth (Fig. 5). Squid caught in 111-183 m (364-600.2 feet) had a mean length of 11.7 cm (4.3 inches) while those collected at 184-367 m (603.5-1,203.8 feet) had a mean length of 18.9 cm (7.4 inches). Squid <6 cm (<2.3 inches) were conspicuously absent from my samples. The smallest *I. illecebrosus* collected off Newfoundland in May 1946-53 were rarely less than 10 cm (3.9 inches) and averaged 14 cm (5.5 inches) in mantle length (Squires, 1957). Juvenile short-finned squid, <6 cm (<2.3 inches), off the southeastern coast are either pelagic and not vulnerable to our gear, or, more probably, move into the sampling area after reaching 6 cm (2.3 inches). The smallest squid (modal length 10 cm or 3.9 inches) collected south of Cape Hatteras were most numerous during spring. Modal lengths ranged from 15 to 21 cm (from 5.9 to 8.2 inches) during other seasons.

Table 3.—Percent occurrence of *Illex illecebrosus* in different seasons and depth zones. Parentheses enclose the total trawls per season per depth zone. Means represent percent occurrence in all trawls pooled by season or depth zone.

Depth (m)	Spring	Summer	Fall	Winter	$\bar{x}$
9-18	0(28)	0(48)	0(18)	0(50)	0
19-27	0(24)	2(50)	0(18)	2(45)	1
28-55	3(35)	2(66)	0(19)	0(59)	1
56-110	4(28)	15(41)	7(14)	0(41)	6
111-183	10(21)	34(29)	20(10)	10(21)	20
184-367	45(20)	52(29)	50(8)	52(23)	50
$\bar{x}$	8	13	8	6	

No sexually mature males or females were collected in this study although some large males carried spermatophores. Although there may be a winter spawn south of Cape Hatteras with recruitment to the continental shelf in spring, more data are needed to substantiate this. Squires (1967) concluded that *I. illecebrosus* spawns in deep oceanic waters at an age of 1 year. Spawning occurs during winter, although some individuals may spawn as late as June.

Illex illecebrosus catches by the FV *Pescapuerta Segundo* were relatively small south of Cape Hatteras (lat. 35.2°N), with the greatest catch rate equal to 67 kg/hour (147.4 pounds/hour). In contrast, catch rates near lat. 38.5°N ranged from 4,000 to 15,000 kg/hour (from 8,800 to 33,000 pounds/hour) (Fig. 4). The short-finned squid were not only more abundant north of Cape Hatteras but were also generally larger. Modal sizes at stations where 40 or more individuals were present averaged 14.3 cm (or 5.6 inches) (range: 12-17 cm or 4.7-6.6 inches) south of Cape Hatteras as compared with 16.6 cm (or 6.5 inches) (range: 14-18 cm or 5.5-7 inches) north of Cape Hatteras.

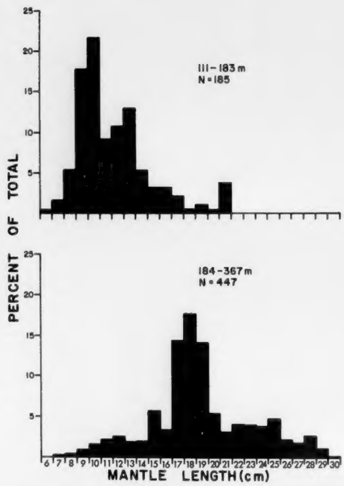

Figure 5.—Length-frequency distribution for *Illex illecebrosus* from all MARMAP samples at 111-183 m and 184-367 m. N is the number of squid measured.

Squid Fishery Potential

Development of a large-scale squid fishery off the southeastern U.S. coast appears highly improbable. MARMAP sampling results indicate that quantities of squid off the southeastern United States are small relative to those found in waters north of Cape Hatteras.

Sampling by the FV *Pescapuerta Segundo* further demonstrated this. There remains, however, the possibility for a small-scale seasonal squid fishery off the southeastern U.S. coast. Consistent monitoring of seasonal

water temperatures could maximize fishing effectiveness by identifying areas where *Loligo* and *Illex* seasonally aggregate. Fishing would probably be best during summer and fall on the continental slope between the 8° and 14°C bottom isotherms. Before large-scale commercial operations begin, however, careful consideration by management agencies is needed to insure rational exploitation of the squid resources, since squid are important forage for economically important finfish (Fields, 1965).

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Squid Fishery in Texas: Biological, Economic, and Market Considerations

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Introduction

Squids are considered to be one of the underdeveloped fishery resources along the Gulf and Atlantic coasts of North America. The recent international implementation of a 200-mile limit, rapidly increasing fuel costs, and a worldwide increase in the demand for squids have provided the impetus to reexamine the squid resources of the U.S. continental shelf. Most of the current activity is centered in the northeastern United States, where stocks of the squids *Loligo pealei* and *Illex illecebrosus* have been exploited for some time, and where both local and overseas markets have been developed (Rathjen, 1973; Serchuk and Rathjen, 1974; Lux et al., 1974; Kolator and Long, 1979).

In contrast, only small amounts of squid have been landed from the Gulf of Mexico, where little market development has occurred. Our purpose is to examine the biological, economic, and marketing constraints that hinder the development of a squid fishery along the Gulf coast of Texas and investigate the concept of squids being a source of income for the existing shrimp fleet. We have chosen this limited geographical area not only because we are familiar with it, but because it typifies the problems faced when introducing an unfamiliar resource to the public.

The concept of utilizing squids as a fishery resource in the Gulf of Mexico is not new. Voss (1960, 1971, 1973) and Rathjen et al. (1977, 1979) stated that squid stocks of unknown size exist in the Gulf of Mexico. Three species occurring over the continental shelf and one species occurring beyond the shelf in deep water have possible commercial potential. These are the loliginid (family Loliginidae) shelf forms: brief squid, *Lolliguncula brevis*; arrow squid, *Loligo plei*; and common or long-finned squid, *Loligo pealei*; and the ommastrephid (family Ommastrephidae) offshore species, the orange-back squid, *Ommastrephes pteropus*. These species can be identified by keys and descriptions presented by Voss (1956), Voss et al. (1973), and Cohen (1976). Presently the only directed fishery for squids in the Gulf of Mexico is a very small-scale fishery that takes place in the fall near Progreso, Mexico, in the state of Yucatan (LaRoe, 1967; Voss, 1971). At night fishermen in small boats use torches and small tethered live fishes (the halfbeak *Hemiramphus* sp.) to attract *L. plei* within range of dipnets. Additionally, all three loliginid squids are taken in bottom trawls as a bycatch of the Gulf shrimp fishery (Hildebrand, 1954, 1955). While most are discarded along with the rest of the bycatch, a small amount is sold at a low price for bait or human consumption.

Biological Considerations

Our characterization of squid populations along the Texas Gulf coast is derived from three sources. Data on commercial landings of squids in Texas are from annual summaries published by the National Marine Fisheries Service (NMFS) in cooperation with the Texas Parks and Wildlife Department. Additional information on squid population parameters came from a 3-year (1975-77) survey sponsored by the U.S. Bureau of Land Management (BLM)[1] of the south Texas offshore continental shelf from the Mexico-U.S. border to Matagorda Island. Similar data were obtained from 924 stations undertaken by the Marine Biomedical

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ABSTRACT–Presently no major squid fishery exists in the Gulf of Mexico, although the shelf forms Loligo pealei, Loligo plei, *and* Lolliguncula brevis *occur throughout the Gulf. We examined the constraints that hinder the development of the fishery, using Texas as a model. Reported incidental catches of squids in shrimp bottom trawls are low, but if markets were developed shrimpers could reduce their monthly losses in the first 6 months of the year by up to 11 percent. Several biological, economic, and marketing problems were identified that indicate a squid fishery is not viable in Texas at this time, although future potential for one exists.*

[1]Environmental studies, South Texas Outer Continental Shelf, Biology and Chemistry. 1979. Reports submitted to the Bureau of Land Management by the University of Texas, Marine Science Institute, Port Aransas Marine Laboratory, Port Aransas, TX 78373.

Institute (MBI)[2] as part of a program to supply live squids for neuroscience research.

The general areal and bathymetric distribution of the four squids was determined by combining the BLM and MBI survey data (Fig. 1). Each species occupies a primary depth range, but these vary both seasonally and from year to year. These ranges overlap, and it is not uncommon to catch the three inshore loliginid squids in a single trawl.

Lolliguncula brevis is a small squid with a maximal mantle length (ML) of 90 mm (3.6 inches). Specimens from the BLM study collected with a standard 10.7-m (35-foot) footrope Gulf shrimp trawl (flat net) had a mean mantle length of 42 mm (1.68 inches) and weight of 6.2 g (0.2 ounce). This squid is usually associated with low-salinity water between 17 and 30 ppt and is found primarily in bays and near shore out to a depth of 20 m (65.6 feet). It is periodically excluded from the coastal bays by low temperatures in the winter (Gunter, 1950) and by very low salinities during peak periods of spring and summer freshwater runoff.

Loligo plei and *L. pealei* are larger animals reaching mantle lengths of 250 and 285 mm (10 and 11.4 inches), respectively. Trawl-caught squids are smaller; *L. plei* had a mean mantle length of 66 mm (2.6 inches) and a mean weight of 6.7 g (0.2 ounce), while the average *L. pealei* measured 69 mm (2.76 inches) ML and weighed 14.5 g (0.5 ounce). *Loligo plei* is usually caught between 20 and 75 m (65.6 and 246 feet) where salinities exceed 30 ppt. *Loligo pealei* is primarily found between 40 and 183 m (131 and 600 feet) in salinities above 33 ppt.

Ommastrephes pteropus attains an adult size of over 350 mm (14 inches) ML but its mean size in our collections is 197 mm (7.9 inches) ML. This squid is an oceanic species that occasionally is taken in depths as shallow as 183 m (600 feet).

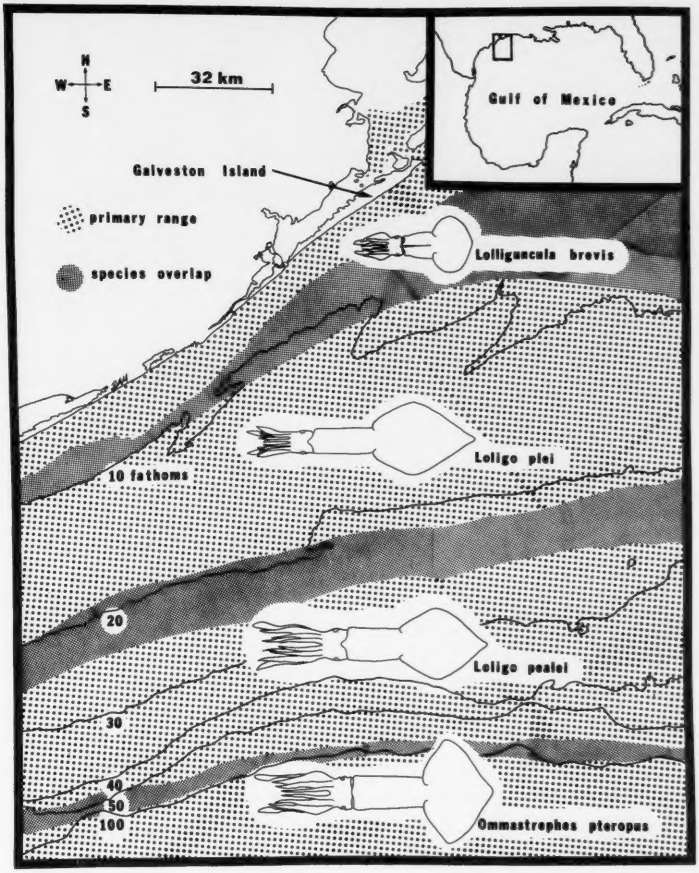

Figure 1.—The approximate areal and bathymetric distribution in summer of four squid species of commercial potential on the Texas continental shelf south of Galveston, Tex.

Alternate methods of capturing squids other than by bottom trawl have been tested in the MBI study in the western Gulf of Mexico. Other loliginid squids, notably *Loligo opalescens* in California (Kato and Hardwick, 1976), group together in large spawning or feeding congregations and are vulnerable to capture by a lampara net or purse seine. No similar congregations of the three Gulf of Mexico loliginid species have been reported, and our few attempts to capture these species at night with encirclement nets and night lights have had very limited success from a commercial standpoint. However, unpublished data from 24 NMFS-sponsored trials in the northeastern Gulf of Mexico (Wickham, 1971) with purse seines and night lights

[2]Hixon, R. F. 1980. Growth, reproductive biology, distribution and abundance of three loliginid squid species (Myopsida, Cephalopoda) in the Northwest Gulf of Mexico. Doctoral dissert., Univ. Miami, Coral Gables, FL 33149, 92 p.

Table 1.—Location of catch, total catch, value, and price per kilogram of all squids landed in Texas ports between 1961 and 1978. Catch weight in kilograms.

Year	Open Gulf waters	Galveston & Trinity Bays	Other bays	Total catch	$ value	$ Price per kg
1961				5,262	1,128	0.21
1962	12,565			12,565	2,770	0.22
1963	16,965			16,965	3,884	0.23
1964	10,297		363	10,660	2,350	0.22
1965	10,387		454	10,841	2,390	0.22
1966	9,253	544	408	10,206	2,300	0.23
1967	4,445	318	544	5,307	1,019	0.19
1968	4,536	318	227	5,080	1,223	0.24
1969	2,404	318	408	3,130	699	0.22
1970	2,767	1,633		4,400	909	0.21
1971	2,449	1,315	544	4,309	1,508	0.35
1972	1,225	1,089	136	2,449	763	0.31
1973	1,225	816	408	2,449	783	0.32
1974	4,717	1,678	363	6,759	2,676	0.40
1975	1,905	907	136	2,948	1,423	0.48
1976	3,765	5,126	363	9,253	4,595	0.50
1977	3,765	1,542	952	6,260	4,144	0.66
1978				7,025	4,450	0.63

Table 2.—Monthly squid landings (kilograms) reported from all Texas ports between 1962 and 1977.

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.
1962	45	91	136	136	2,177	1,860	4,491	1,860	272	635	816	45
1963	91	45	318	1,724	3,084	3,221	3,493	1,542	2,041	590	499	318
1964	318	454	181	1,225	1,043	862	1,769	1,043	998	1,225	1,089	454
1965	181	136	680	1,633	2,132	3,583	1,270	499		181	318	227
1966	454	227	635	363	1,134	1,179	3,266	1,179	499	408	408	454
1967	272	272	635	181	227	1,361	1,134	544	272	45	318	45
1968		91	91	45	363	272	408	2,223	318	816	408	45
1969	45		91	91	136	408	680	136	227	771	454	91
1970	91	45	45	136	45	318	2,359	272	544	227	272	45
1971		91	45	454	1,270	1,043	363	91	408	272	272	
1972		136	181	45	227	1,134	318	45	181		181	
1973		45		91	1,043	181	408	91	227	136	181	45
1974	454	408	1,588	816	181	1,361	499	544	363	181	181	181
1975		454	136		91	363	771	318	91.	318	272	136
1976		227	862	3,402	3,221	363	318	227	363	181	45	45
1977		45	136	544	590	136	907	953	1,588	726	499	136
Mean	122	173	360	680	1,060	1,103	1,403	723	525	420	388	142

Table 3.—Projected daily catch of each squid species and combined monthly yield of all squids from nine depth strata[1].

	Depth (m)								
Item	0-10	11-20	21-30	31-40	41-50	51-75	76-100	101-125	126-250
No. of daytime tows	6	18	18	18	18	18	18	12	18
Lolliguncula brevis									
Mean no./tow[2]	49.2	60.1	13.4	4.0	0.1				
No. squid/day[3]	1,575	1,923	429	128	3				
Yield in kg/day (6.2 g/squid)	9.8	11.9	2.7	0.8					
Loligo plei									
Mean no./tow[2]	3.3	7.2	45.5	57.2	32.7	23.6	6.9	0.7	0.1
No. squid/day[3]	106	230	1,456	1,830	1,046	755	221	22	3
Yield in kg/day (6.7 g/squid)	0.7	1.5	9.7	12.3	7.0	5.0	1.5	0.1	
Loligo pealei									
Mean no./tow[2]			2.2	2.4	13.1	7.0	15.1	8.5	8.7
No. squid/day[3]			70.4	76.8	419	224	483	272	278
Yield in kg/day (14.5 g/squid)			1.0	1.1	6.1	3.2	7.0	3.0	4.0
Total daily yield (kg)	10.5	13.4	13.4	14.2	13.1	8.2	8.5	4.0	4.0
Monthly yield (kg)[4]	210	268	268	284	262	164	170	80	80

[1]Mean catch based on data for entire year.
[2]Each tow was 15 minutes.
[3]Calculated by extrapolating mean catch in 15 minute tow to 8 hours.
[4]Based on 20 days of trawling per month.

show that up to 15 percent of the catch was squids[3].

Another possible capture method for *Ommastrephes pteropus* and both species of *Loligo* is to attract them to lights at night and capture them with squid jigs. Our experience on both research and exploratory fishing vessels with hand-held jigs and squid jig machines has indicated that only *Ommastrephes pteropus* might eventually be taken in commercial quantities with jigs.

A third alternative is the introduction of large high-speed midwater trawling gear similar to that which is presently producing high squid catches in the U.S. east coast offshore squid fishery. Our conclusion is that the three loliginid squids currently would best be caught by using existing commercial shrimp trawling gear. Catches would be higher during daytime because squid undergo a vertical diurnal migration (Summers, 1969; Serchuk and Rathjen, 1974; Rathjen et al., 1979). They are near the bottom during the day and up in the water column at night.

Squid landings statistics reported by NMFS show when and where squids are caught, but the records are incomplete because an unknown amount of squid is not reported, and they do not differentiate the catch into species. Total reported squid landings in Texas between 1961 and 1978 averaged 6,931 kg (15,248 pounds) per year and ranged from 2,449 kg (5,388 pounds) in 1972 and 1973 to 16,965 kg (37,323 pounds) in 1963 (Table 1). The highest monthly mean catches, 680-1,403 kg (1,496-3,087 pounds), are recorded between April and August and the lowest mean catches, 122-173 kg (268-381 pounds), occur between December and February (Table 2).

High catches during the spring and early summer partially reflect increased effort of the shrimp fleet during this time, but similar trends in squid abundance are also found in the BLM and

[3]Wickham, D. A. 1979, Office of Policy and Planning, National Marine Fisheries Service, NOAA, Washington, DC 20235. Personal commun.

Table 4.—1978 monthly and annual costs and returns[1] for an average owner-operated Gulf shrimp trawler in Texas. Source: Tydlacka, 1979.

Item	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
Returns													
Kilograms[2]	1,187	1,236	1,093	962	1,370	1,896	3,292	3,640	2,706	2,718	2,462	2,173	24,735
$ Price/kilogram[2]	5.91	5.91	5.84	6.21	4.67	3.26	4.08	5.44	7.16	7.34	8.95	8.47	6.15
$ Gross revenue	7,011	7,300	6,387	5,981	6,402	6,186	13,427	19,819	19,393	19,953	22,038	18,397	152,294
$ Costs													
Variable costs													
Supplies & repairs[3]	3,352	3,212	3,619	3,967	3,789	4,821	5,797	5,263	5,834	5,948	4,857	6,031	56,490
Crew shares[4]	1,402	1,460	1,277	1,196	1,280	1,237	2,685	3,984	3,879	3,991	4,408	3,679	30,458
Packing[5]	195	203	179	158	225	311	540	597	444	446	404	356	4,058
Total variable costs	4,949	4,875	5,075	5,321	5,294	6,369	9,022	9,824	10,157	10,385	9,669	10,066	91,006
Total fixed costs[6]	2,397	2,367	2,375	2,467	2,460	2,412	2,480	2,562	2,496	2,416	2,426	2,552	29,410
Total costs of operations	7,346	7,242	7,450	7,788	7,754	8,781	11,502	12,386	12,653	12,801	12,095	12,618	120,416
Total $ profit or $ loss from operations	−335	58	−1,063	−1,807	−1,352	−2,595	1,925	7,433	6,740	7,152	9,943	5,779	31,878

[1]Based on budgets of vessels from 20 to 29 m in overall length.
[2]Recalculation from original pounds to kilograms resulted in slight rounding differences.
[3]Includes fuel, nets, groceries, repairs, ice, miscellaneous supplies, and maintenance.
[4]Based on share agreement of 20 percent.
[5]Based on $2.05/kg.
[6]Includes insurance, interest, overhead, and depreciation. Based on vessel cost of $166,000.

MBI data. Over 80 percent of the reported squid catch is taken on the continental shelf in the open Gulf of Mexico. The remainder is taken in coastal bays, the most important of which are Galveston and Trinity Bays (Table 1).

Presently it is not possible to make statistically defensible estimates of the squid resources of the Texas Gulf Coast. The best information available comes from the BLM trawling survey (footnote 1) that adopted a nonrandom sampling scheme. The object of the extensive BLM study was to determine which species were present within the survey area and the relative abundance of these species between sampling stations. With these limitations in mind, we used the BLM data (footnote 1) to estimate a catch rate for squids with commercial shrimp trawl gear at various depths (Table 3). This estimate was made from 144 daytime trawls taken in three seasons (winter, spring-summer, and fall) in 1976 and 1977 from 24 fixed stations arranged on four inshore-to-offshore transects. Each sample consisted of a 15-minute bottom tow with a standard 10.7-m Gulf shrimp trawl. To summarize, the data in Table 3 indicate that projected catches are low (current maximal estimates of 284 kg (625 pounds) per month) and that the greatest amounts are caught between shore and a depth of 50 m (164 feet).

Table 5.—Break-even yield at alternative prices for squid for an average Gulf shrimp trawler in Texas between January and June in 1978 dollars.

Squid price	Jan.	Feb.	March	April	May	June	Total
$0.66/kg							
Kilograms	16,021	15,555	16,692	17,897	17,390	20,086	103,642
$ Value	10,574	10,266	11,017	11,812	11,477	13,257	68,403
$2.20/kg							
Kilograms	2,188	2,082	2,342	2,564	2,446	3,104	14,727
$ Value	4,813	4,580	5,152	5,641	5,381	6,829	32,399
$4.40/kg							
Kilograms	913	869	977	1,070	1,020	1,295	6,143
$ Value	4,017	3,824	4,299	4,708	4,488	5,698	27,029

Economic Considerations

What conditions in terms of price, catch rates, and fishing season would induce a typical Gulf shrimper to fish for squid? We analyzed these questions by considering squids either the subject of a directed fishery or as part of an incidental fishery. Table 4 shows the 1978 monthly and annual costs and returns for an average owner-operator Gulf shrimp trawler of 20-29 m (65.6-95 feet) overall length.

Over the calendar year 1978 the owner-operator earned an accounting profit from the shrimp fishery of $31,878. Notice, however, that total profit from operations is negative for the first 6 months of the year (except February) and positive for the last 6 months of the year. Based solely upon economic considerations, we estimated how much squid an owner-operator would have to land to just break even if he fished exclusively for squids for the first 6 months of the year. Break-even yield is defined here as the yield that just covers the total costs of operations, so that total profit equals zero. It will be assumed that variable costs remain the same.

Table 5 gives the break-even yield and gross value of the hypothetical total squid landings under alternative price conditions from January through June. For convenience we chose values of $0.66, $2.20, and $4.40 per kilogram of squid ($0.30, $1.00, and $2.00 per pound). The lower price of $0.66/kg is the recent average price of squid along

the Texas coast (Table 2), whereas the \$4.40/kg is the approximate price received by trawlers off the northwest coast of Africa (Griffin et al., 1979). At a price of \$0.66/kg, the catch just to break even for each trawler must average over 17,000 kg (37,400 pounds) of squid per month, or total over 100,000 kg (220,000 pounds) for the entire 6-month period. As the price moves up to \$2.20/kg, the break-even quantity of squids drops considerably to a 6-month total of 14,727 kg (32,400 pounds). At \$4.40/kg, the 6-month break-even quantity would be reduced to 6,143 kg (13,515 pounds). Our biological estimates indicate that even at a price of \$4.40/kg the break-even quantity is higher than our estimated monthly catch rate.

Clearly, a directed fishery for squids is not feasible at this time along the Texas coast using bottom trawls. It may be possible, however, for squids to be an incidental fishery, especially during the first half of the year when shrimping alone does not provide a profit margin.

Since squid catches are highest between April and August (Table 2), we have made some estimates of how much the average owner-operator might reduce his losses during this period by selling squids that are caught during daytime shrimp trawling. Using a value of \$0.66/kg and a projected catch rate of 284 kg (625 pounds) per month, the owner-operator pulling one trawl would receive \$187 per month for whole, unprocessed squids. Assuming crew shares and packing charges are the same as for shrimp, the owner-operator would clear only \$103.

Some boats pull two trawls and their take would be about \$206 per month. While these figures are low, they can reduce the monthly loss. In April, for instance, \$206 per month for squids would reduce the \$1,807 loss by 11 percent. Losses would be further reduced if markets and products for other incidental finfishes could be simultaneously developed (Juhl and Drummond, 1976; Blomo and Nichols, 1974; Nichols et al., 1975).

Market Considerations

From all the foregoing information it is obvious that for squids to be an alternative fishery in Texas the highest price possible should be attained. The marketing task required is formidable and touches three areas of consumer acceptance criteria: 1) Perceptual appearance, 2) physical attributes, and 3) buying decision perspectives. Many of our observations are based on an analysis of seafood consumption and product perceptions in Texas (Gillespie and Houston, 1975).

In terms of perceptual appearance, domestic consumers hold a strong bias against both the name "squid" and the traditional retail merchandising method of marketing squids in the whole, unprocessed form (Kalikstein, 1974). Most consumers do not want to eviscerate and dress animals for meal preparation. On the positive side, processed squid that has been eviscerated and skinned has a preferred white-colored flesh. Its appearance is further enhanced when the mantle is split, resulting in an appealing fillet-like form (Berk, 1974). An alternative name such as "calamari" (Italian for squid) would seem to make the product more appealing for the uninformed user[4].

The physical attributes of preferred seafoods are that they be tender and mild-tasting. In spite of favorable taste qualities, squid flesh tends to be tough or rubbery when it is improperly cooked, due to the presence of several layers of connective tissue in the muscle (Otwell and Hamann, 1979a) that are absent in finfish.

Based upon current technology, neither pounding nor mechanical tenderizing equipment can achieve the degree of tenderness of most other cooked seafood. However, Otwell and Hamann (1979b) concluded that to insure tender cooked squid, mantle meat should be cut into longitudinal strips which have less muscle fiber resistance, and boiled for less than 5 minutes to avoid excessive mantle dehydration. If further tenderization is desired, boiling squid meat 40-60 minutes will tenderize it very well, although at some sacrifice of moisture content.

An additional consideration is that larger squids (e.g., *Loligo pealei* or *Ommastrephes pteropus*), which cost less to process and prepare, are usually tougher than the smaller squids (*Lolliguncula brevis*). If the goal is to produce a squid product with acceptable taste and texture, it may be more advantageous to develop a market using smaller squids. This would be beneficial since trawls generally select for smaller squids.

From a buying decision perspective squid must be economical, nutritious, and easy to prepare. The retail price of whole squid is attractive relative to other seafood; however, the market price increases significantly after processing. Currently, squids must be hand-processed[5], and they have between one-third and two-thirds yield; therefore, a dealer price of \$0.66/kg (Table 1) to a processor becomes a conservative yield price of \$1.98/kg. When the processor's costs for labor, packaging, and profits are added, the price of processed squid easily exceeds \$2.20/kg. The pricing mechanisms of the distribution channel through frozen food brokers, distributors, and wholesalers results in a retail price of \$3.50-\$4.15/kg (\$1.59 to \$1.89/pound). At these prices squid competes with finfish fillets, and it is more likely that the consumer will choose the more familiar fish instead of squid.

[4]Such a strategy has proved beneficial in the promotion of squids in the northeast United States. The New England Fisheries Development Program published a consumer-oriented squid preparation and cooking pamphlet with recipes entitled "Squid (calamari): the versatile shellfish." (U.S. Gov. Print. Off.:1975-601-510/20, Region No. 1). Forty-six other calamari recipes are found in "Let's cook squid the European way" by K. Hryniewiecka, published in 1976 by the University of California Sea Grant Marine Advisory Program and the California Department of Fish and Game, Long Beach, CA 90802.

[5]Recently, several innovative processing machines have appeared on the market. One example is the Steen III skinning machine (Skinning Machines, Inc., Stonington, CT 06378) that can quickly skin squids. (Personal commun., 1979, with W. S. Otwell, Department Food Science, University of Florida, Gainesville, FL 32611.) Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Nutritionally, squid meat has a high value (Varela et al., 1962) because of its low fat but high protein content (Matsumoto, 1958; Kahn et al., 1974). Concerning preparation, no widely acceptable processed precooked squid product has yet been developed. Consumers currently must use squid in raw form and must take cooking steps (see above) that require about the same amount of time as preparing other meats.

There are two domestic marketing approaches to be considered at this time. One is through the larger-scale consumer and restaurant trade route, and the other is to introduce the product on a small scale as a specialty item in local seafood or ethnic restaurants. The first approach requires relatively complex and extensive channels of distribution that must first be developed within Texas to insure wide market acceptance. To overcome consumer unfamiliarity with squid and gain mass market acceptance, a well-coordinated promotion program by large seafood processors or a restaurant chain must be instituted[6]. To introduce squid to a regional market area the size of Texas is expensive (estimates exceed $200,000) and the outcome is uncertain.

The second marketing approach seems more appropriate at this time. Small-scale introduction seems best done initially by small Texas processors who could introduce processed squid speciality items such as stuffed squid or breaded squid rings and strips to local small markets, including certain urban ethnic populations which are familiar with squid, and coastal areas or seafood restaurants where one might expect to find squid as a menu item. Such ethnic communities exist in many Texas cities, including a large Vietnamese community that has recently relocated on the Texas coast. Once squid gains public awareness and acceptance on this small scale, steps may be taken toward the development of mass market acceptance.

[6]An example of such a successful program was that for the common Gulf croaker, *Micropogon undulatus*, in which the Texas A&M Sea Grant Program, Texas Parks and Wildlife Service, Handy Andy grocery chain, and Pat Pace Fisheries combined to successfully promote consumer awareness of this product in San Antonio, Tex. (Personal commun., 1979, with J. P. Nichols, Department of Agriculture Economics and Rural Sociology, Texas A&M University, College Station, TX 77843.)

Summary

Several major problems have been identified that indicate a squid fishery is not a viable alternative in Texas at present. Stocks of three loliginid squid species are present in the northwestern Gulf of Mexico, but reliable biological estimates of squid population size must first be made. Squids would be best fished initially by the existing shrimp trawler fleet as an incidental catch and not as a directed fishery. Eventually, fishing methods conducive to capturing the fast-moving schooling squids must be employed for optimal catches. For squids to become an attractive resource, fishermen and processors must be able to receive much higher prices than those now available. Such increases can only be attained when sufficient demand exists either from domestic or overseas markets. Because significant obstacles in terms of product name, texture, and marketable form now exist in the domestic market, either overseas or small-scale domestic markets with squid specialty items should be established first. The decision to expand to wider domestic markets should be postponed until the question of the size of the squid resource, the marketing obstacles pointed out previously, and sufficient economic return to the fishermen and processors can be answered.

While these conclusions are generally negative, it must be pointed out that with changing conditions squid could eventually be fished commercially on the Texas coast. As an example, estimates 15 years ago for the potential of a New England squid fishery were low. Since that time landings by both foreign and domestic fishermen have increased dramatically as new fishing grounds, more advanced capture methods, and overseas and domestic markets have been developed.

A similar course of events could transpire in the northwestern Gulf of Mexico. As the economic situation changes, the Gulf shrimp industry may find it necessary to utilize the bycatch and begin to slowly alter fishing and processing methods to include the more efficient harvest of specific bycatch organisms, including squids.

Acknowledgments

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Experimental Fishing for Squid With Lights in Nantucket Sound

ELIZABETH H. AMARAL and H. ARNOLD CARR

Introduction

Harvesting squid by light attraction techniques has been practiced on the U.S. west coast since late in the 19th century. The first successful technique used torches, small skiffs, and purse seines in the waters off Monterey, Calif. By 1953, the fishery along southern California became dependent upon lamps, principally the incandescent type, combined with a power assisted brail or purse seine.

The successful use of lights in the west coast squid fishery relates to the unusual behavior of the target species, *Loligo opalescens*. This species, like *L. pealei* on the east coast, moves into the coastal waters to spawn. While in shoal waters, *L. opalescens* will often rise and "float" at the surface, although this behavior is neither consistent nor predictable. Artificial lights have provided a means to concentrate these squid near the surface frequently enough to allow for commercial exploitation.

The first documented attempt to use artificial lights to attract and "float" the longfin squid, *Loligo pealei*, was in 1974, when a contract to the University of Rhode Island (URI) was funded through the New England Fisheries Development Program. A series of trials in waters south of Rhode Island and Massachusetts demonstrated that squid could be attracted and concentrated under 1,000-watt incandescent lights[1]. However, the squid never floated quietly in a manner in which they could be brailed or pumped aboard. Recommendations from this effort resulted in a second series of trials in 1975 by URI wherein attempts to purse seine squid were not successful since no large concentrations were ever encountered[2].

This project capitalized on the existing technology from Japan and the U.S. west coast and previous findings on the east coast by URI, and applied these methods to Nantucket Sound, an area where squid are known to be abundant in May and June.

The principal investigators for this project are Fred Powell and Mark Simonitsch, owners of a company that operates five fish weirs in Nantucket Sound. Captain Powell has set fish traps for 30 consecutive years and has caught squid in them each year. He first became interested in this type of project in 1973, when he made small scale experiments with lights on the fish traps with encouraging results. Further investigation led to the initiation of this project.

The five operational phases of the project are as follows: 1) A series of preliminary evaluations of gear performance using herring as a target species; 2) a secondary evaluation of gear by encountering the early arrival of squid at the western entrance to Nantucket Sound; 3) a concentrated effort to catch squid in the Sound using prior experience with weather and squid distribution to direct the vessel to various flats, holes, and shoals; 4) an evaluation of lights near and in the participants' traps; and 5) experiments with various lights and gear.

[1]Allen, R. B., and R. E. Taber. 1974. Light attraction for squid in New England waters. Univ. Rhode Isl., Dep. Fish. Mar. Technol., Narragansett. Unpubl. manuscr., 20 p.

[2]Taber, R. E. 1976. Purse seining for squid using light attraction methods at night. Univ. Rhode Isl. Mar. Advis. Serv., Narragansett. Unpubl. manuscr., 10 p.

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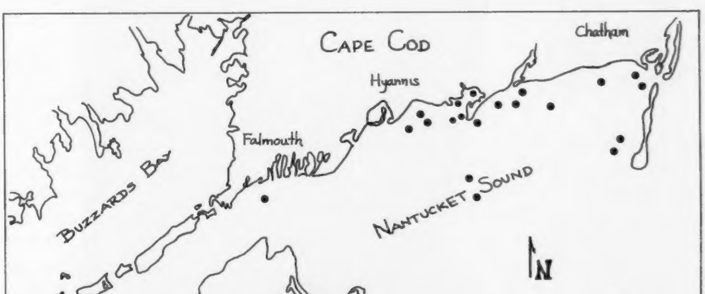
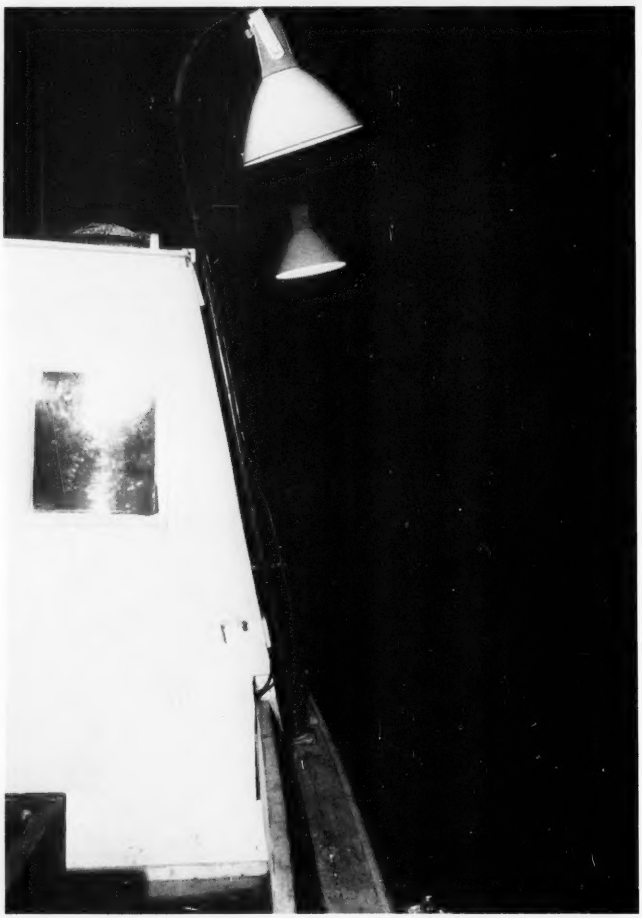


Nantucket Sound squid survey areas.



The squid research vessel *Payday* (left), photographed by Paul Kemprecos. Below is a night view of the vessel's lights.

Vessel, Rigging, and Operation

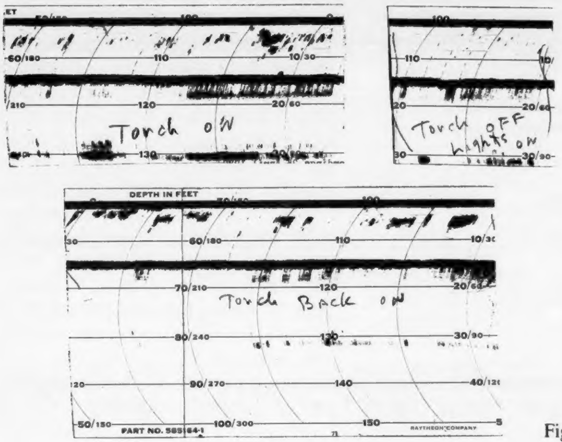
The principal investigators used a 12.5 × 3.4 × 1.1 m wooden vessel suitable to work in extreme shoal water. Modifications and rigging began in January 1979. A 6-kW electrical generator, powered by a natural gas engine, was installed astern to provide 110 volt A.C. power. Lights were installed forward, midships, and astern approximately 3 m above the water on both sides of the vessel *Payday*.

Initially, three 750-watt and three 1,500-watt incandescent lamps were mounted on the port and starboard sides, respectively. These lights illuminated the water surface out to 5-6 m abeam of the vessel. Two 175-watt mercury vapor lights later replaced two of the 1,500-watt incandescent bulbs. Also used were a 300-watt incandescent underwater light and a 1,000-watt quartz halogen lamp. The quartz halogen lamp was mounted on the gunwale.

A Raytheon Explorer III[3] depth recorder was the principal instrument used to locate concentrations of squid. Suspect concentrations showing on the recorder were verified by hand lining with Japanese-type squid jigs. Three killdevils and a large checker located on the aft deck were constructed to brail and hold the catch.

The *Payday* departed port before dusk, allowing sufficient daytime to steam toward a predetermined location in Nantucket Sound. When the vessel arrived on station, the crew searched for suspected concentrations of squid with the depth sounder, prior to anchoring. After dusk, the lighting operation began and would continue, weather permitting, until dawn. If the weather became foul, but still workable, or if no concentrations of squid were seen on the depth sounder, the *Payday* moved

[3]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.



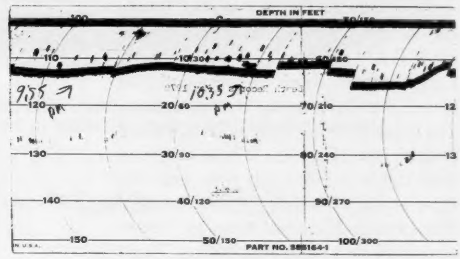


Figure 2.—Depth recordings 2 May 1979.

Figure 1.—Depth recordings 25 April 1979.

Table 1.—Squid lighting trips.

Date (1979)	Location[1]	Surface water temp. (°C)
4/16	Just outside Stage Harbor, Chatham	5.6
4/17	South of Falmouth Harbor	6.7
4/18	Off Bass River buoy	5.6
4/19	Off Hyannis Harbor breakwater	7.8
4/20	Centerville Harbor	8.9
4/23	Off Chatham (Middle Ground) and Harwich; Rodgers Shoal (at tip of Monomoy Island)	8.9
4/24	South of Bass River—trip terminated by foul weather	8.9
4/25	Hyannis Harbor and just outside	11.7
4/30	Bass River breakwater	12.2
5/ 2	Hyannis Harbor (outside harbor)	8.9
5/ 3	Hyannis Harbor	12.2
5/ 4	Hyannis Harbor	14.4
5/ 5	Centerville Harbor	14.4
5/ 6	Lewis Bay	14.4
5/ 7	Lewis Bay	15.0
5/ 8	Centerville Harbor; Collier and Gannet Ledges (south of the harbor)	15.0
5/11	Lewis Bay	17.2
5/12	Lewis Bay	17.2
5/14	Dogfish Bar (near fish trap) and off Point Gammon, Great Island	17.8
5/15	West of Point Gammon and into Lewis Bay	
5/16	Collier Ledge, Gannet Ledge to Hyannis Harbor	17.8
5/17	Lewis Bay—trip terminated because of foul weather	17.8
5/21	Bishop and Clerks; Hyannis Harbor	14.4
5/22	Southeast of Bass River breakwater (fish trap)	16.7
5/25	Lewis Bay; Hyannis Harbor	17.8
5/29	Lewis Bay breakwater; off Point Gammon	19.4
5/31	Bishop and Clerks; Point Gammon and Dogfish Bar (fish trap)	18.9
6/ 1	Bishop and Clerks to Broken Ground	16.7
6/ 2	WNW of Nantucket breakwater	17.8
6/ 3	North side, Nantucket Pier	16.7
6/ 5	Pleasant Bay, Chatham to Round Cove, Harwich	16.7
6/10	Chatham Harbor, Pleasant Bay	

[1]Refer to chart 13237 Nantucket Sound and Approaches.

to another location. Details on the operation and weather for each trip were recorded on a logsheet.

Vessel Trials

The *Payday* made her initial light attraction trial in Nantucket Sound on 16 April. A total of 32 night trips were made between 16 April and 10 June (Table 1). Each trip consisted of anchoring at one station or more. Nineteen stations were inside bays and harbors bordering Nantucket Sound and 26 stations were in Nantucket Sound proper. Between 16 and 20 April, the vessel traversed the Sound from Stage Harbor, Chatham, to Nobska Point, Falmouth, primarily checking the lighting and secondarily looking for signs of squid. Both incandescent lights and a kerosene herring torch were used. On two evenings herring were attracted to the torch where they swam actively near the vessel, chasing bait, and marking well on the recorder. When the torch was extinguished and the incandescent lights turned on the herring disappeared, both visually and on the recorder. When the lights were turned in toward the centerline of the vessel, about 0.6 m (2 feet) from the gunwale, heavy clouds of fish were seen on the recorder. These were shortly verified visually as sea herring (Fig. 1).

The *Payday* crew first saw squid on 30 April, 0.8 km (0.5 mile) southwest of the Bass River breakwater. The water temperature was 12.2°C. As the vessel traversed the leader of a fish trap, six squid were seen at the water surface; however, jigging was not successful.

Between 2 and 8 May the *Payday* concentrated efforts in Hyannis Harbor, Lewis Bay, and Centerville Harbor. By this time, squid were prevalent inshore over most of the Sound and reported in the inner bays and harbors where people were successfully jigging them under dock lights. Three 1,500-watt incandescent lights were used almost exclusively; 750-watt bulbs were already found to be less effective in attracting squid.

On 2 May the recorder showed concentrations of squid on the bottom (Fig. 2). A total of 175 pounds (79.3 kg) were caught by jigging just off the bottom with two hand-held jigs. Squid were also observed actively chasing bait near the surface throughout the evening. On 4 May, 20 squid could be seen within 0.6-0.9 m (2-3 feet) of the surface for just a few moments before darting away. Jigging success was erratic; only 30 were jigged over a period of several hours. Division biologists examined several squid and found them ripe.

On 6 May the *Payday* worked Lewis Bay where the water temperature was 14.4°C and the depth 2.4 m (7.9 feet). Large concentrations of squid could be seen 1.2 m (3.9 feet) below the surface. The depth recorder indicated something deeper, too (Fig. 3). When bow and stern lights (1,500-watt) were shut off, these squid seemed to "crowd" more. The captain described them as "more stationary and more bunched up" than previously observed. When bow and stern lights were lighted and turned inboard, the squid crowded closer to the boat. Jigging during this period seemed to scatter squid near the vessel. When the 750-watt bulbs were also lit and all lights were out over the side, squid circled the boat. They gathered back under the 1,500-watt lamps when the 750-watt bulbs were extinguished. During the nights of 7 and 8 May, the lack of squid activity, both visually and on the recorder, was attributed to a bright, nearly full moon. From 20 to 30 squid would appear below the surface and rapidly disappear. Squid were jigged infrequently.

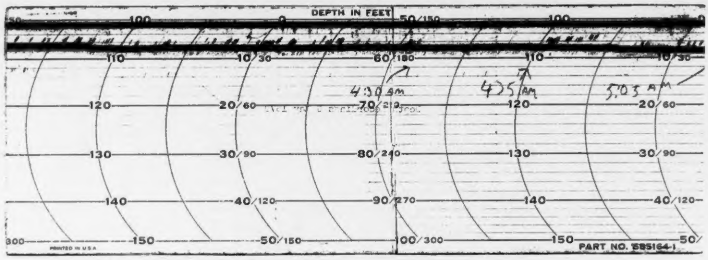


Figure 3.—Depth recordings 6 May 1979.

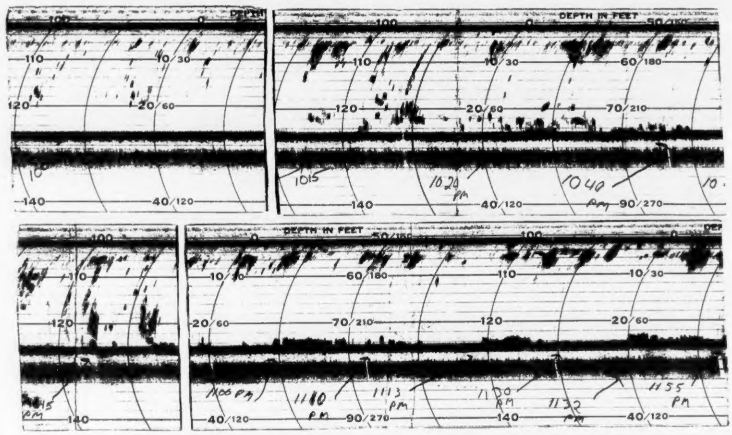


Figure 4.—Depth recordings 2 June 1979.

After two nights off during the full moon, the crew continued 12 trips into Lewis Bay and just offshore, to Collier Ledge and Bishop and Clerks. The captain saw the greatest amounts of squid in Hyannis Harbor. The three 1,500-watt bulbs were mostly used with the additional two 750-watt bulbs used only occasionally. On 16 May small squid (15-20 cm or 5.9-7.9 inches) were sighted for the first time in schools numbering 50-60 in Hyannis Harbor.

On 21 May squid were jigged near the bottom but few were seen near the water surface. Seven squid were examined: Five ripe females had no sperm in the mantle and of two males, one was spent and one was ripe. A Rhode Island vessel utilizing mercury vapor lights and lift net set over the side anchored nearby. A brief discussion with the crew of this vessel revealed that they had successfully attracted and caught squid in previous years with mercury vapor lights.

On 22 May, two 175-watt mercury vapor lamps replaced the mid and aft 1,500-watt incandescent lights aboard the *Payday*. The initial trial with new lights was directed near a fish weir off Bass River where heavy squid landings were reported. The two mercury vapor fixtures alone were lighted the entire night. Very few squid were observed throughout the night in contrast to recent evenings; however, they could be jigged at a constant rate of one every 3-5 minutes. A lift net, fashioned after that on the Rhode Island vessel, was rigged over the *Payday*'s starboard side on the night of 25 May. The net proved ineffective due to the short length of the boom and slow net retrieval speed. Squid activity, visually and on the recorder, was minimal during the evening; the net was thereafter abandoned.

At the end of May, as the squid dispersed from the inner bays bordering Nantucket Sound, the crew of the *Payday* concentrated more on the shoal areas in the Sound. On 1 June, the vessel anchored off Bishop and Clerks (south-southeast of Hyannis Harbor). Little registered on the recorder and the crew jigged only a few squid.

On 2 June the *Payday* travelled to Nantucket. They fished west-northwest of the Nantucket breakwater in the vicinity of heavy squid dragging activity. Two mercury vapor lights and two 750-watt incandescent lights were turned on shortly after 2100 hours when the recorder indicated some small targets. At 2200 hours the marks became heavier, particularly between 1.2 and 6 m (3.9 and 19.7 feet), but also along the bottom (Fig. 4). Squid would appear occasionally chasing bait but were not easily jigged. Between 2240

and 0030 hours the recorder showed the heaviest targets to date; these were near the bottom. As bottom markings increased, those at the 3-m (9.8-foot) depth decreased or disappeared. Squid observed this night were all small (15-20 cm or 5.9-7.9 inches) and appeared more frequently under the incandescent than the mercury vapor lights, all positioned over the side. Squid movements were described as "spooky" as they would settle under the lights for several minutes, scatter, and then reappear once again. This activity continued all evening and may have been related to a bright moon and several dogfish, *Squalus* sp., circling the vessel. During the following night (3 June) inside Nantucket Harbor, no appreciable numbers of squid showed throughout the evening. The last trial was on 5 June in Pleasant Bay, Chatham. With the exception of one pulse of activity when 13 squid were jigged in 10 minutes, recorder marks were sparse and the night ended unproductively.

On several evenings two other light fixtures were rigged for experiment, a 300-watt underwater incandescent light and 1,000-watt quartz halogen lamp. The latter was placed just over the gunwale. The former was tried for usually 1 hour at a time per given night, attracting little or nothing other than two dogfish. The quartz halogen lamp never attracted squid but did attract large schools of unidentified small (2.5-10 cm or 1-3.9 inch) "bait fish." As long as the light was illuminated, these small schools, swimming against the current, would remain at the surface directly under the light. "Bait fish" were also seen gathering under the incandescent lights, but not under the mercury vapor lights.

Discussion

Although the *Payday* operated in areas of known squid concentrations, squid were not attracted in commercial quantities to the various lights used nor were squid observed to float quietly near the surface.

Squid were abundant in Nantucket Sound and its adjacent harbors during the period of this experiment. On

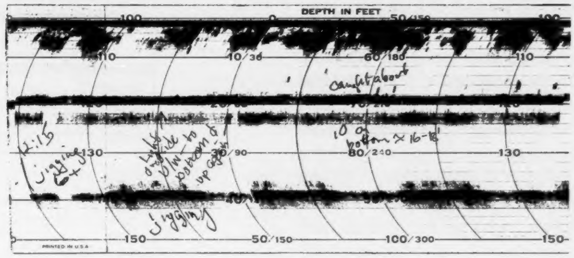


Figure 5.—Depth recordings 21 May 1979.

11 May, 10 days after the crew of the *Payday* sighted their first squid, the Massachusetts Division of Marine Fisheries spring resource assessment cruise found squid at six out of eight stations that were scattered throughout the Sound. Commercial draggers trawled successfully in permitted waters of the Sound, first off Falmouth and later off Nantucket catching approximately 680.4 t (1,500,000 pounds) of squid. The fish traps, located along the northeast shore of Nantucket Sound, reported landings of 394.5 t (870,000 pounds). When the contractors operated around their traps during the last three weeks of May, the catch from the traps was 134.6 t (297,000 pounds) 75 t (165,000 pounds); and 36.9 t (81,000 pounds) per week, respectively.

The crew of the *Payday* and Division biologists did question the reliability of the Raytheon Explorer III depth recorder in registering concentrations of squid. The high frequency of the recorder (200 KHz) had good range resolution in shallow depths (<50 m or <164 feet) (Forbes and Nakken, 1972). However, the recorder would frequently record "noise" or turbulence near the surface (Fig. 5). These markings were thought to be large schools of fish or squid but visual observation in clear water proved that no fish or squid were near the surface.

Incandescent lights were the primary type of light chosen for this experiment because, on the west coast, it is the only successfully used fixture. The captain of the Rhode Island fishing vessel *Summer Dawn*, encountered on 21 May, said that prior to this year, mercury vapor lights were the most successful[4]. The use of mercury vapor lights on the *Payday* late in May proved ineffective. Squid were not as readily attracted to the mercury vapor lights as they were to the incandescent lights when both types were illuminated.

Positioning of lights on the vessel revealed some interesting patterns in *L. pealei* behavior. This behavior was not only observed during this experiment, but in the two previous URI trials. The first (1974) URI trial rigged four 1,500-watt lights directly out over the rail, two on each side of the vessel. The lights on the *Payday* were swung out over the rail, but at least 3 m (9.8 feet) from the water surface. Squid were often seen at the periphery of the brightly illuminated area, approximately a meter below the surface. When the lights were turned inboard the squid concentrated closer to the vessel. Preference of squid to the periphery of the illuminated water or to the shadow of the vessel when lights were turned inboard was reported previously (Ben-Yami, 1976).

Squid behavior inside the illuminated area during this experiment also paralleled that during the URI trials. Five or six squid followed a jig to the surface and then darted away. Squid remained with the vessel throughout the night (on the recorder) but were seen only sporadically. Small schools rose around the boat, lingered momentarily, then disappeared.

The experiment continued through

[4]C. Snow, FV *Summer Dawn*, Little Compton, R.I. Personal commun.

the spring spawning season for squid. Masses of eggs were first picked up on the nets in the fish weirs during mid-May. On the west coast, *L. opalescens* is expected to float sometime during the middle of spawning[5]. Floating then occurs approximately 50 percent of the nights fished. This behavior did not occur with *L. pealei*. Therefore, behavior of the two species appears radically different.

Experiments on the behavior of longfin squid to lights were recently undertaken at the Marine Biomedical Institute of Galveston, Tex. Trials of various types of lights and techniques resulted in the conclusion that *L. pealei* are not as phototactic as other species[6]. The effect of lighting operation around the fish traps was inconclusive. Both types of lights elicited no new behavior from the squid; however, squid were occasionally seen near the surface and were frequently jigged. The depth recorder indicated targets throughout the water column (Fig. 6). These targets were believed to be squid since squid was the predominant catch in the trips during this period.

The brail net and the lift net were not an effective means of harvesting during this operation since the squid never

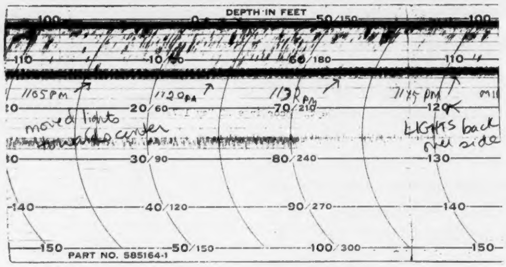


Figure 6.—Depth recordings 22 May 1979.

floated or appeared docile. Jigging resulted in a 79.5-kg (175-pound) catch on 2 May but thereafter jigging did not yield large quantities of squid.

The potential use of the jig as a means to commercially harvest *L. pealei* is questionable. It was considered of little commercial use in these waters during the squid spawning season by Arnold et al. (1974). The purse seine has been tried but never used effectively. Its use in the waters of Nantucket Sound and its embayments would be difficult due to swift currents, irregular bottom, and shoal areas.

Acknowledgments

To the crew of the *Payday*, Robert Nickerson, Captain, Russell Chase and Tom DeFriend, we extend sincere thanks for continual cooperation and enthusiasm through long "squid-less" nights. Fred Powell and Mark Simonitsch provided guidance to all of us with their knowledge of Nantucket Sound and squid behavior in the Sound. We offer special thanks to Warren F. Rathjen, New England Fisheries Development Program, and Philip G. Coates, Director, Massachusetts Division of Marine Fisheries, for their support and input into this contract.

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Experimental Pair Trawling for Squid in New England

ALAN J. BLOTT

Introduction

In pair trawling, two boats are used to tow a single trawl. The boats are far enough apart to spread the trawl horizontally, thereby eliminating otter boards and the high hydrodynamic drag associated with them. Two boats can fish a larger trawl than can be fished by either one alone; and with the reduced drag, the trawl can be towed faster with a probable increase in catch (Larsson, 1959). In addition, there are no trawl warps in front of the net to frighten the fish. Midwater and bottom pair trawling for various fish species has been used effectively in other countries for many years (Taber[1]).

The objective of this study was to test the feasibility of harvesting winter or longfin squid, *Loligo pealei*, in inshore waters with a bottom pair trawl.

Procedure

Two pair trawlers which had previously been used in the squid fishery were chartered by the New England Fisheries Development Program (NEFDP) to fish up to 12 days in Nantucket Sound during the spawning season when squid are inshore in shoal water. They were the 85-foot (26-m) *Karen Sue* with 300 hp and the 57-foot (17.4-m) *Susan and Lori* with 335 hp. A fisheries engineer from the Gloucester Laboratory of the Northeast Fisheries Center was on board the *Karen Sue* during the experiment.

Originally, the NEFDP proposed the boats use their existing Christensen[2] pair trawl, a herring trawl with headrope and footrope lengths of approximately 185 feet (56.4 m). However, the skippers volunteered to build a squid pair trawl of their own design which they believed would be more effective than the herring trawl. The NEFDP agreed and the new squid trawl (Fig. 1) was used during the project.

Five trips were made. The first trip, of 3 days, was spent on exploratory fishing and gear familiarization in Block Island and Nantucket Sounds (Fig. 2).

Trip 2, lasting 1.5 days, took place on the quahog ground between Tuckernuck Shoal and Nantucket Harbor, traditionally an area of good squid catches. During this trip, two tows were made after dark. All other tows in the experiment were made during daylight hours.

During the first two trips, the squid trawl was fished in the same manner as the herring trawl had been fished. Two warps with a ten-to-one scope were used from each boat. Weights were secured to each lower warp 10 fathoms from the wing and there were no floats. With the trawl rigged this way, the vertical mouth opening of the trawl was 4 fathoms, as measured by the echo sounder on another boat.

The boats fished Nantucket Sound and the quahog ground for 2 days on Trip 3. Prior to the trip, modifications were made to the gear to make it dig harder on the bottom. Chain was added to the sweep (footrope), and the trawl was fished with the top warp on each side 1.5 fathoms longer than the bottom warp.

Trip 4 was spent testing the gear in Rhode Island waters for half a day. Further modifications were made to allow the trawl to dig harder. The trawl was towed with only one warp from each boat leading to two 20-fathom bridles (legs) on each side of the net. The weights were moved to the warp end of the legs on each side, and three inflated poly floats were attached to the headrope.

On Trip 5, the net was rigged the same as on Trip 3. The trip lasted 2 days and the quahog ground and Nantucket Sound were fished.

Results

The five trips totaled 9 fishing days and took place between 12 May and 13 June 1977. Fifty-one tows were made with a total squid catch of 14,200 pounds (6,441 kg) (Table 1). Twenty-five of these tows were made on the quahog ground and yielded approximately 315 pounds (143 kg) per hour. In the rest of Nantucket Sound, the average catch was about 160 pounds (73 kg) per hour.

The two tows made after dark resulted in small catches with the amount caught dropping to one-half of that from the last tow made just before dark.

The skippers found, by continually checking with other squid fishing vessels in the same area, that the catch rate

[1]Taber, R. E. 1976. Feasibility demonstration of bottom pair-trawling for herring and other finfish. S.N.E. Fisheries Development Group, U.S. Dep. Commer., Gloucester, Mass. Contract No. 03-6-043-35122, Jan. to June 1976, 5 p.

[2]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

ABSTRACT–The use of a bottom pair trawl for catching squid was examined in this study. The object was to determine the commercial feasibility of harvesting winter squid with the pair trawl. The trawl used was designed by the vessel captains involved in the study. Study results show that further experiments are needed using additional trawl designs and that the influence of speed and other fishing parameters need to be investigated.

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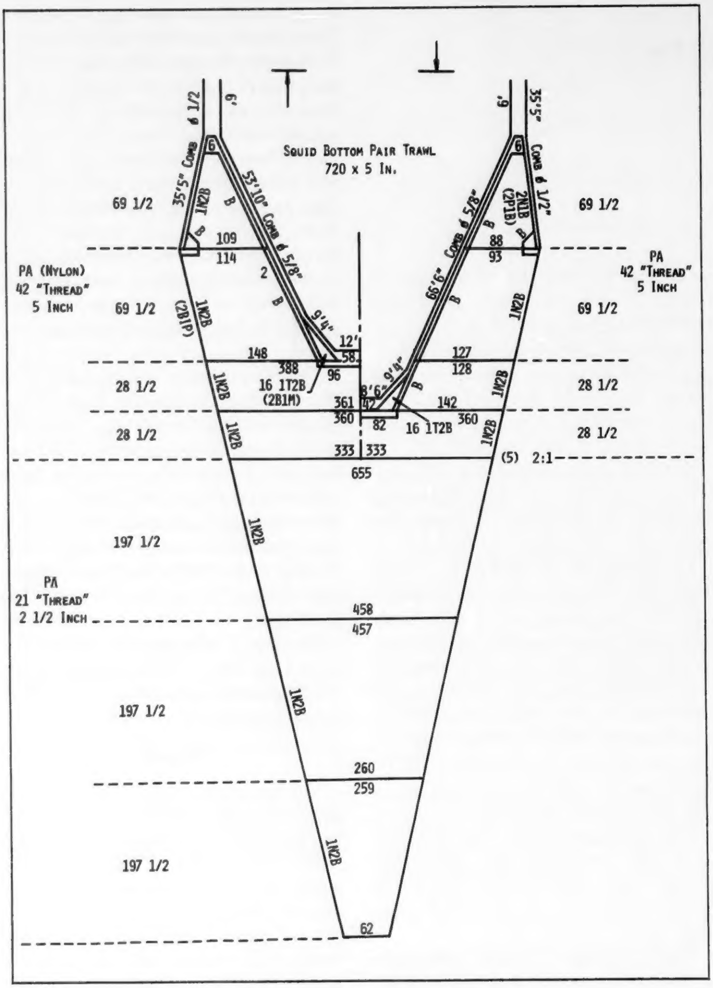

Figure 1.—Squid bottom pair trawl.

Table 1.—Squid catch by trip and location: NS = Nantucket Sound, QG = Quahog Ground, and BIS = Block Island Sound.

Trip	Date	Tow	Location	Time of setting	Squid catch (bu)	Catch rate lb/h
1	5/12	1	NS	0715	0.25	30
		2	NS	0855	0	0
		3	NS	1025	0.75	80
		4	QG	1215	0.75	60
		5	QG	1415	Net fouled	
		6	QG	1530	2.5	200
	5/13	7	QG	0605	0.5	40
		8	QG	0740	1.25	100
		9	NS	1000	0.5	40
		10	NS	1350	2	480
		11	NS	1745	0.5	160
	5/14	12	BIS	0600	0.75	60
		13	BIS	0720	1	80
		14	BIS	0930	0	0
		15	BIS	1130	0	0
		16	BIS	1345	0	0
2	5/26	17	QG	0825	3	240
		18	QG	0945	6.5	520
		19	QG	1110	6	320
		20	QG	1305	16	640
		21	QG	1520	11.5	460
	[1]	22	QG	1745	6	240
	[1]	23	QG	2005	5	200
	5/27	24	QG	0545	9	480
		25	QG	0745	6	320
3	6/4	26	NS	0825	2.5	200
		27	NS	0940	4.5	240
		28	NS	1145	7.5	400
		29	QG	1450	2	107
		30	QG	1700	2.5	133
	6/5	31	NS	0640	4	213
		32	NS	0840	6	320
		33	NS	1120	0.25	60
		34	NS	1430	1	160
		35	NS	1515	0	0
4	6/8	36	BIS	0615	0	0
		37	BIS	0825	0	0
		38	BIS	0935	0.25	20
		39	BIS	1150	0	0
5	6/12	40	QG	0645	8	427
		41	QG	0845	13	693
		42	QG	1045	6	320
		43	QG	1245	9	480
		44	QG	1445	7	373
		45	QG	1645	8	320
	6/13	46	QG	0545	5	267
		47	QG	0745	6	274
		48	QG	0950	4	183
		49	NS	1245	0.5	80
		50	NS	1350	0	0
		51	NS	1600	0	0

[1]Night tows.

of the pair trawl was approximately the same as the single-boat trawls. Pair trawlers must catch at least twice as much as single boats in order for pair trawling to be viable.

One of the two best days of fishing occurred during Trip 2 with the gear used as originally rigged when the catch rate was 380 pounds (172 kg) per hour, and the other was after the modifications were made with a catch rate of 430 pounds (195 kg) per hour on Trip 5. However, the abundance of squid could have changed significantly in the time between the two best days.

Discussion

At the end of the experiment, the skippers felt they were still a long way from optimizing gear performance. They felt the trawl was not fishing hard enough on the bottom. That was the principal reason for the gear changes between cruises. Catch rates did not offer conclusive evidence in support of this contention. They also thought the 5-inch (127-mm) mesh in the wings of the trawl may have been too small. FAO (1976) indicated that Japanese

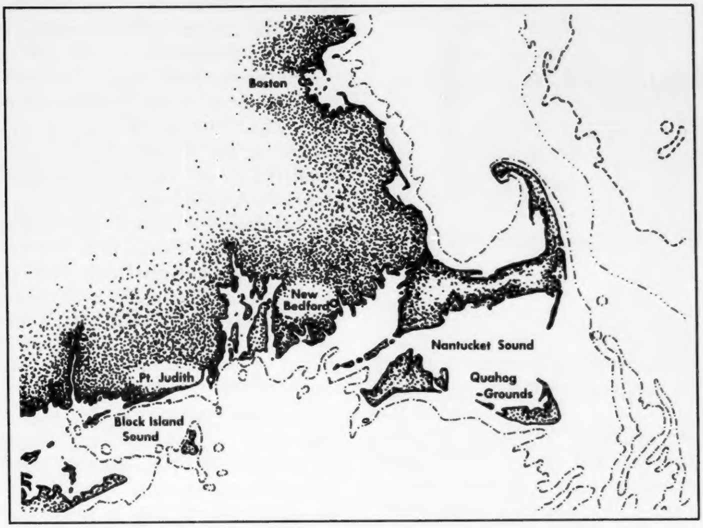

Figure 2.—Chart of fishing areas.

squid fishermen used 9.4-inch (240-mm) mesh in the outer wings and 4.7-inch (120-mm) mesh in the inner wings. French squid trawls use 3.9-inch (100-mm) mesh in the wings, while the Germans have used trawls with 5.7-inch (145-mm) and 7-inch (180-mm) mesh in the wings. In the California lampara net fishery for *Loligo opalescens*, 6-inch (152-mm) and 9-inch (230-mm) meshes are used.

Mesh size in the wings of the experimental pair trawl could be increased somewhat. The value of an increase is questionable as other nations are successfully fishing with mesh both larger and smaller. In any case, the maximum mesh size probably should be not greater than 9-10 inches (229-254 mm) because squid, reportedly, are not "herded" well with large mesh or warps (FAO, 1976). The ability of a pair trawl to herd well because of the diverging warps is usually an advantage of this type of gear. This may not be the case in the squid fishery.

Another problem with the experimental pair trawl may have been the small overhang of the square. All nets mentioned above had overhangs 2-3 times as deep as the pair trawl. This could have allowed the squid to avoid capture by swimming over the net.

Speed is another parameter to consider and is probably one of the most important. Towing speed during the experiment was only about 2.5 knots at 1,600 rpm. The foreign nets mentioned above are bigger and are towed at 3-6 knots; thus, they are more difficult for the squid to actively avoid. If possible, within the constraints of the available horsepower, a towing speed of 3.5-4 knots should be tried.

Conclusion

At the onset of this experiment, it was assumed that pair trawling would be a viable method for harvesting squid. Although the results did not corroborate this, further investigation is warranted. The study has shown that the net is sensitive to variations in rigging parameters. Future studies should look at the performance of this net in relation to changes in trawl speed and variations in other operational and rigging parameters, and should investigate alternate net designs which take foreign experience into account.

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Experimental Jigging for Squid off the Northeast United States

DOUGLAS LONG and W. F. RATHJEN

Introduction

Light attraction jigging is a fishing technique specifically developed for catching squid. Jigging for squid is one of the most important methods used in coastal squid fisheries in Japan. In Japan about 95 percent of the common squid, *Todarodes pacificus*, which represents a major part of the squid catch, is caught by jigging (Yajima and Mitsugi, 1976).

In North America there has been a traditional fishery for squid in Newfoundland where recent catches have approached 50,000 t annually[1]. Experimental squid fishing using jigging and light attraction has also been conducted in nearshore New England situations through the New England Fisheries Development Program (Amaral and Carr, 1980) and in the Gulf of Mexico (Rathjen et al., 1979). During 1978 and 1979 the Canadian Government sponsored commercial level demonstration fishing for squids using jigs in the waters east of Nova Scotia. Early reports of this experience suggested substantial catches could be made on a regular basis[2].

In 1973 the Japan Marine Fishery Resource Research Center sent the RV *Hoyo-Maru No. 51* followed by the RV *Hoyo-Maru No. 63* in 1974 and 1975 to conduct exploratory squid jigging from Cape Hatteras to the Grand Banks. Fishing south of Georges Bank along the edge of the continental shelf yielded 103,475 kg (227,645 pounds) of *Illex illecebrosus* in 112 days of fishing (Ichikawa and Sato, 1976). These catches were taken in July and September of 1973 and 1974, respectively.

The Polish Deep Sea Fisheries Company Odra equipped three of their vessels with Japanese squid jigging gear to conduct exploratory fishing. Their investigations began in May near the Falkland Islands in the South Atlantic. Successful catches of *Illex argentinus*, with daily catches in excess of 8,000 kg (17,600 pounds) were made. Each vessel spent about 45 days working there, after which two of the vessels proceeded to the Fishery Conservation Zone (FCZ) off the U.S. northeast coast to investigate areas along the continental slope from east of Cape Henlopen to southeast of Cape Cod. The following is a presentation of observations of their squid jigging operations made while on board these Polish vessels during August and September 1979.

Fishing Vessels and Gear

The *Wigry SWI-173* (Fig. 1), built in 1962, is a 61-m (200-foot) side trawler of 797 gross tons powered by a 1,375 horsepower engine. The *Murena SWI-193* is a 69-m (226-foot) B-23 class

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Figure 1.—Polish research vessel *Wigry*, 61 m long. Jigging gear is on the well deck.

[1]G. V. Hurley, Department of Fisheries and Oceans, St. John's, Nfld., Canada. Personal commun., Nov. 1979. See also Hurley (1980).
[2]David Lemon, Fisheries Development Branch, Department of Fisheries and Oceans, P.O. Box 550, Halifax, Nova Scotia, Canada. Personal commun.

stern trawler of 1,005 gross tons powered by a 1,620 horsepower engine.

Each vessel is equipped with 10 automatic jigging machines (model MD-3SE[3]) manufactured by the Towa Denki Seisakusho Co., Ltd. (Fig. 2). The machines were mounted on the bow of the *Murena* and on the well deck of the *Wigry*. A windlass drum is mounted on each end of a levelwind shaft which passes through the motor assembly. Each drum can fish one line to a depth of 180 m (590 feet). A depth control knob enables each machine to be adjusted to fish at the depth of the squid. The set and hauling speed can be varied from 20 to 80 rpm according to weather and fishing conditions. Experience proved that 60 rpm (59.8 m or 197 feet per minute) was the best running speed. In case of a sudden entanglement of jigs or lines the machine stops automatically. The "jigging" motion is produced by the six-sided oval shaped drums. Each unit is equipped with a push button control box on a cord which allows one man to control several units.

The jigs consist of a plastic body with two sets of barbless hooks (Fig. 3). The body varies in length from 48 to 72 mm (from 1.9 to 2.9 inches) and is either soft or hard plastic of various colors, including clear. They are both luminescent and nonluminescent. Jigs are classified according to the length of the barbs. The "shelf jig" used to catch *Illex illecebrosus* has two rings of 16 hooks each 11 mm (0.4 inch) in length. Figure 4 shows a comparison of a 22-cm (8.6-inch) mantle length *Illex* to two shelf jigs. "Ocean jigs," used for larger species of squid such as *Illex argentinus*, have two rings of 14 hooks 16 mm (0.6 inch) in length.

The jigs are attached in a series spaced 80-100 cm (31-39 inches) apart with 20-50 jigs per line. The line is made of clear monofilament which varies in diameter according to depth. The jigs at the bottom end of the line are tied with about 0.9 mm (0.035 inch) diameter line while those near the surface

[3]Mention of trade names, products, or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

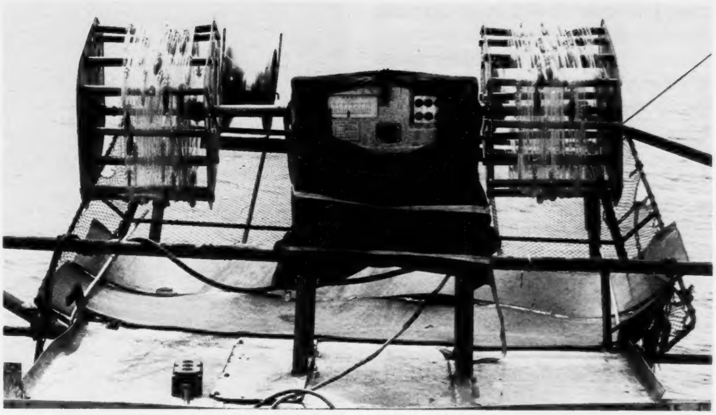

Figure 2.—Automatic jigging machine mounted on the bow of the vessel. Electric motor unit is protected by a canvas cover. Note the three-button control box.

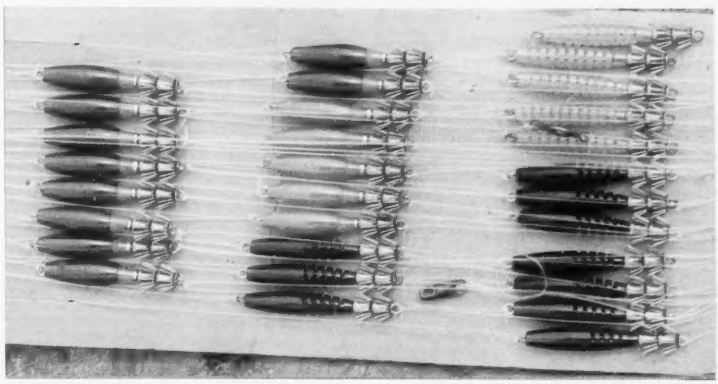

Figure 3.—One set of pre-tied shelf jigs with swivel ready to attach to the main line.

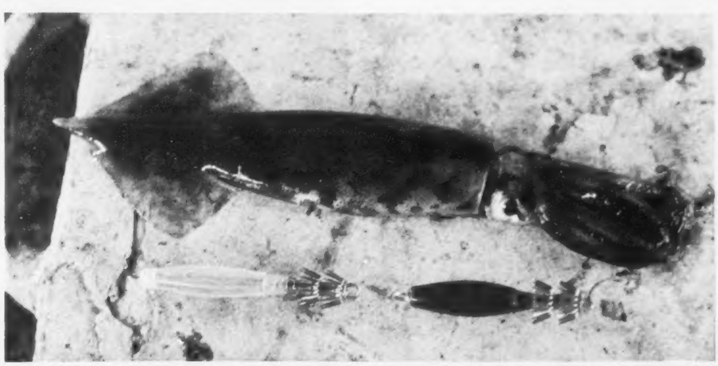

Figure 4.—A 22-cm (mantle length) *Illex* and two shelf jigs.

have 1.15 mm (0.045 inch) diameter line since the latter receive more strain. This series of jigs is attached by means of a swivel to a 100-m (328-foot) main line 2 mm (0.08 inch) in diameter. After a few nights fishing, this line scheme was modified by retying all the jigs using 1.9 mm (0.075 inch) diameter line in an effort to reduce breaking lines. A 1-kg (2.2-pound) lead sinker is tied at the bottom of each line to keep the gear vertical as it enters the water. When strong currents are encountered, another 0.5-kg (1.1-pound) of lead is added to each line. The jig line runs from the drum to a plastic roller mounted on the outboard end of a metal frame that is covered with netting (Fig. 5).

The vessel *Murena* had two rows of incandescent lamps suspended from steel cables at intervals of 34 cm (13.3 inches) over the area of the jigging machines. There are 48 lamps in all, 24 along each side. Of these, 14 are 4,000 watts each and the remainder, 2,000 watts each. The lights are 270 cm (8.9 feet) above the deck and 82 cm (2.7 feet) inboard from each side of the vessel. The distance from the deck to the water line is about 5 m (16.4 feet). This produces a shade zone of 1.6 m (5.2 feet) along side of the vessel. The outboard plastic rollers of the jigging machines are positioned so the jig lines pass through the boundary zone of light and shade of the vessel. The *Wigry* has a similar lighting scheme except that the 48 lamps were all 2,000 watts.

Figure 5.—Overhead view showing 2,000-watt and 4,000-watt lamps suspended over the jigging machines.

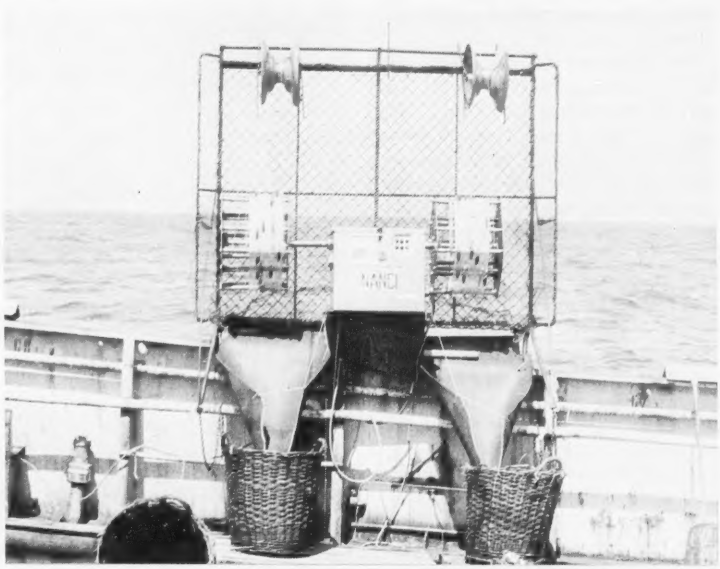

Figure 6.—Jig machine with metal mesh-covered frame turned up during the day. Note the rubber ramps that guide falling squid into wicker baskets.

Fishing Operations

When on the fishing ground the vessels begin to move into position around 1600 hours. Taking into consideration water currents and weather conditions, the vessel is positioned near the area where previous catches were made. Once in position a sea anchor (nylon parachute, 23 m (75.4 feet) in diameter) is deployed from the bow, thus allowing the vessel to drift slowly with the current. A mizzen sail is hoisted in the stern to keep the vessel heading into the wind.

The lamps are turned on between 1900 and 1930 hours (depending on the season) and automatic jiggers start between 1930 and 2030 hours. The lamps and echo sounder run continuously throughout the night. When an indication of squid is detected a few machines

Figure 7.—Crewman scraping squid from the jig machines into the waterflow trough.

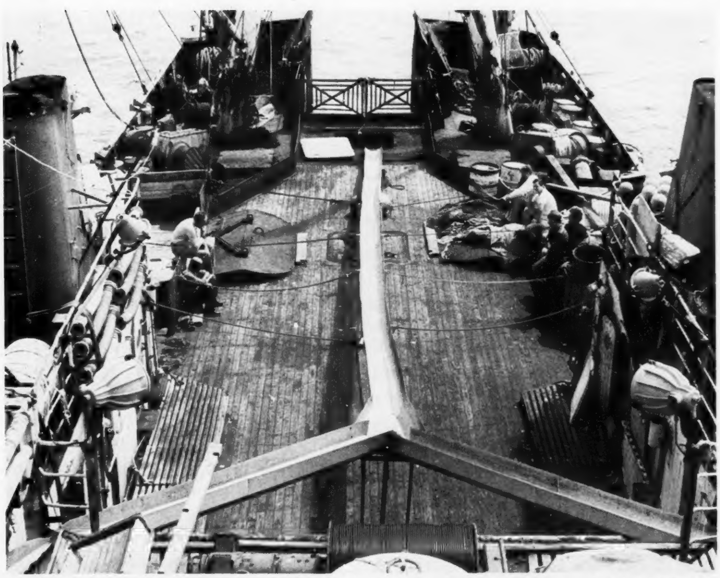

Figure 8.—Waterflow trough, leading from under the jig machines, carries squid down to the trawl deck hatch which leads to a factory holding bin.

are set so the jigs will fish at the depth indicated. The expectation is that the deeper running jig lines will lure the squid close to the surface. Once the squid are near the surface or "floating" all the machines are adjusted so that the last jig coming off the drum enters about 1 m (3.3 feet) below the water surface before the line is retrieved.

Hooked squid coming up on the jigs flip off between the outboard roller and the line drum falling onto a frame lined with netting. The *Wigry*'s crew scrapes the squid off the frame into wicker baskets that are periodically collected and dumped down a chute leading to the factory (Fig. 6). The *Murena* has a waterflow trough under the machines that carries the catch down to the trawl deck where it funnels through a hatch and into a holding bin in the factory (Fig. 7, 8).

Processing Operations

Once in the factory, the squid were washed with seawater and packed into 10-kg (22-pound) capacity metal trays. When the squid are uniform in size no grading is necessary. The trays of squid are frozen in a Freon contact plate freezer unit. The frozen block of squid has a core temperature of −24°C (−10°F). Each block of frozen squid is glazed by dipping in a hot freshwater bath. The blocks are packed into cardboard boxes (three blocks to a box) and stored in a freezer hold. When the plate freezers are full, the squid left on the packing table are covered with about a 3-cm (1.2-inch) layer of salt flake ice.

Fishing Areas

The vessels worked in an area from east of Cape Henlopen to southeast of Cape Cod. The area of investigation (Fig. 9) is divided into five parts: Lydonia Canyon to Hydrographer Canyon (A), Veach Canyon (B), Atlantis Canyon (C), Block Canyon (D), and Spencer Canyon (E) (Fig. 9). Water depth ranged from 150 m (492 feet) to over 1,000 m (3,280 feet). The majority of the fishing effort was concentrated in areas A and B which was based on the captain's success in finding squid near these canyons in previous years.

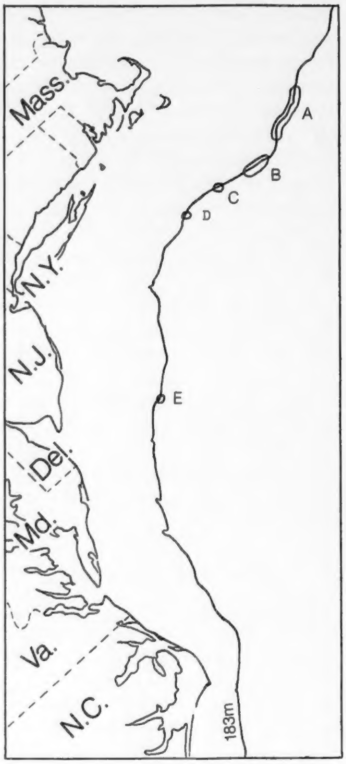

Figure 9.—Areas of investigation.

Table 1.—Squid catches of the *Wigry*.

Date	Area	Start and stop times	Number of jigs fishing	Water depth (m)	*Illex* catch (kg)	*Ommas-trephid* catch (kg)	Total catch/ jig/hour (kg)
8/2-3	B	2030 h 0530	700	284 207	1,620.0	0.6	0.257
8/3-4	B	2035 0535	700	246 151	2,465.0	0.0	0.391
8/6-7	B	2030 0520	700	246 685	3,185.0	—	0.515
8/7-8	B	2035 0530	700	173 264	2,980.0	—	0.477
8/8-9	B	2050 0540	700	261 430	1,355.0	—	0.219
8/9-10	B	2010 0530	700	175 157	550.0	0.0	0.084
8/10	B	1930 2130	700	202 176	1.5	0.0	0.001
8/11-12	B	1915 0505	700	233 235	1,615.0	0.0	0.235
8/16-17	E	2015 0535	700	264 214	1,460.0	0.0	0.223
8/17-18	D	2000 0515	700	196 348	2,370.0	1.0	0.366
8/18-19	A	2025 0530	700	474 245	6,205.0	0.0	0.976
8/19-20	A	2035 0520	700	303 398	3,995.0	—	0.652
8/20-21	A	1930 0530	700	270 296	1,280.0	—	0.183
8/21-22	A	1930 0530	700	500 347	930.0	—	0.133
8/22-23	A	2000 0535	700	341 890	2,000.0	—	0.298
				Total	32,011.5	1.6	0.347

Table 2.—Squid catches of the *Murena*.

Date	Area	Start and stop times	Number of jigs fishing	Water depth (m)	*Illex* catch (kg)	*Ommas-trephid* catch (kg)	Total catch/ jig/hour (kg)
8/4-5	C	2100 h 0530	605	220 185	2	0.0	0.000
8/14	A	0105 0545	605	192 150	15	0.0	0.005
8/14-15	A	1830 0600	605	200 150	1,230	0.0	0.177
8/15-16	A	1930 0530	605	160 920	2,280	0.0	0.377
8/16-17	A	1935 0530	730	240 1,000	6,480	2.3	0.895
8/17-18	A	1945 0530	796	480 210	2,610	0.6	0.336
8/18-19	A	1945 0530	796	320 200	6,060	0.8	0.781
8/19-20	A	2030 0530	796	360 445	750	1.5	0.105
8/20-21	A	2000 0530	796	420 510	2,100	1.4	0.278
8/21-22	A	1955 0540	796	340 580	6,750	0.0	0.870
8/22-23	A	1930 0530	796	290 420	3,060	1.2	0.385
				Total	31,337	7.8	0.423

Catch and Effort

Tables 1 and 2 present the catch and effort data for each vessel. The largest catches of squid were taken in area A. The best catch of 6,750 kg (14,884 pounds) was caught on the west side of Oceanographer Canyon in 340-580 m (1,115-1,902 feet) of water. The average catch of squid per night for the *Murena* was 2,848.8 kg (6,282 pounds) and 2,134.1 kg (4,706 pounds) for the *Wigry*.

The *Wigry* had a substantial increase in its catch rate during the last 13 days in the FCZ. After 25 August the vessel spent 8 days on the east side of Oceanographer Canyon (area A) and had an average catch of 5,000 kg (11,025 pounds) per night. Following this, 3 days were spent at Veatch Canyon (area B) where the catch averaged 5,400 kg (11,907 pounds) per night[4]. A major factor contributing to the increase in catch may have resulted from a change in the vessel's lighting. (See the later section on vessel lighting.)

Japanese research vessels working in an area from Block Canyon to Lydonia Canyon in 1973 and 1974 had a daily

[4]Bell, G. M. Deployment on Polish squid jigging vessel *Wigry* 24 August 1979 to 8 September 1979. Unpubl. cruise rep. on file with NMFS Foreign Fisheries Inspector Program, Otis, MA 02542.

Table 3.—Relationship between environmental factors and the catch of *Illex illecebrosus*.

Date	Water temp. at 0 and 100 m (°C)	Lunar period[1]	Cloud cover[2]	Wind direction	Beaufort scale	Catch/jig/hour (kg)
8/2-3	26.0-13.2	10	8	SW	4	0.257
8/3-4	25.5-13.1	11	6	SW	4	0.391
8/4-5	26.0-13.2	12	0	SW	1	0.000
8/14	17.2-10.5	21.5	0	SW	3	0.005
8/14-15	17.6-11.0	Last quarter	8	SW	4	0.177
8/15-16	—	23	3	W NW	3	0.377
8/16-17	20.0-13.0	24	0	NW	2	0.895
8/17-18	20.5-13.0	25	1	W	1	0.336
8/18-19	20.3-13.1	26	8	SW	3	0.781
8/19-20	19.5-13.0	27	8	SE	3	0.105
8/20-21	19.4-12.9	28	8	NE	1	0.278
8/21-22	18.4-13.3	29	6	NE	1	0.870
8/22-23	21.0-13.4	New moon	8	NW	1	0.384

[1]Based on a 30-day lunar month.
[2]0 = clear skies . . . 8 = total cloud cover.

Table 4.—Lengths[1] and weights of randomly sampled *Illex illecebrosus*.

Date	Latitude N and Longitude W	Range of male length (cm) and weight (g)	Mean	Range of female length (cm) and weight (g)	Mean	No. of individuals sampled: Male	Female
8/3	39°55′ 69°32′	19.5-24.5 80-230	22.2 164	20.5-29.0 100-480	23.5 195	31	12
8/17	40°19′ 68°03′	20.5-23.5 110-250	21.9 196	21.0-24.0 110-400	22.7 212	30	20
8/22	40°11′ 68°29′	20.0-24.5 150-320	22.2 208	21.0-27.0 160-350	23.4 223	65	35
8/23	40°11′ 68°28′	20.5-25.5 190-340	22.4 225	22.0-26.0 190-350	23.8 242	29	31
					Total	155	98

[1]Mantle length to nearest 0.5 cm.

catch rate of 923.9 kg (2,037 pounds) using 26 jig machines on one vessel and 29 on the other (Ichikawa and Sato, 1976). In the present investigation, an average daily catch rate of 2,437 kg (5,374 pounds) was attained using only 10 jig machines per vessel. By contrast during the foreign trawl fishery for *Illex* the catch per vessel day was 9,664 kg (21,309 pounds) in August 1977 (Kolator and Long, 1979). It may be possible to substantially increase the daily catch rate for a trawler vessel with the addition of jigging machines for use at night when trawling is not at its peak.

Small quantities of *Ommastrephes* spp. were caught along with the *Illex*. The *Ommastrephes* were usually caught when the vessel was drifting in depths over 400 m (1,312 feet). One night the *Murena* moved offshore to a depth of 4,753 m (15,590 feet) where 19 kg (42 pounds) of *Ommastrephes* were caught.

On most nights catches of squid would be rather low and sporadic until about midnight at which time they would increase. About midnight, large concentrations of squid often started to form near the surface. The catch rate would peak between 0400 and 0515 hours when extremely large masses of squid were "floating" on the surface sometimes encompassing the entire lighted area around the vessel. On one particular night about 1,200 kg (2,646 pounds) of squid was caught from 2000 to 0330 hours while in the remaining time period (from 0330 to 0530 hours) over 5,500 kg (12,128 pounds) of squid was caught. This phenomena of the jig fishery is referred to as "Asa-mazume" or morning harvest (Flores, 1972).

Environmental Factors

The relationship between certain environmental factors and the catches of *Illex* is presented in Table 3. It has long been recognized that there is a correlation in the jig fishery between squid catches and lunar age. According to Ichikawa and Sato (1976), catches of *I. illecebrosus* during the 15 days around the new moon were 10 times greater than catches taken during the full moon. During the present investigation three poor catches (15 kg (33 pounds) or less) were taken during the full moon period. On lunar day 11 (5 days before the full moon) under heavy cloud cover, a relatively good catch of 2,465 kg (5,435 pounds) was made. It is possible that the negative effect of a full moon is masked by heavy cloud cover which produces a darker night.

The water temperature was taken from each vessel with a bathythermograph. In general the catches were larger in areas where the surface water was 18.4°-26.0°C (65°-79°F).

Strong currents, winds, and seas adversely affected the jigging operation. Frequent tangles would occur sometimes causing the jig lines to break. Tangled and broken jig lines could keep one or more jig machines out of operation for up to 0.5 hour. In an effort to reduce the frequency of tangled lines during foul weather only every other jig machine was operated.

Biological Data

Random samples of *Illex* were taken at various locations. The range and means of lengths and weights is presented in Table 4. In the four samples taken, females consistently showed a higher mean length and weight than males. Males represented 61.3 percent of the 253 squid sampled. Of the females sampled, 89 percent were reproductively immature while 34 percent of the males were maturing and another 23 percent were mature (large

testes and the spermatophore sac contained spermatophores).

When the squid were present on the surface they could be seen feeding heavily on euphausids and small fish. Good fishing may be related to the abundance of plankton and small fish attracted by the lamps. The presence of blue sharks, *Prionace glauca*, did not seem to affect the schooling squid. The only problem they presented was occasionally grabbing a hooked squid causing the jig line to break.

Vessel Lighting

The *Wigry*'s increased catch rate during its last 13 days of fishing could be directly related to the change in the lighting system. A wider shade zone was created along the sides of the vessel by moving the two lines of lamps farther inboard. This adjustment may have provided a wider area with the proper illumination for the squid to see the jigs and react to their motion. Apparently the bright light serves to attract the squid, while the zone of shaded light seems to encourage them to react to the motion of the jigs.

At present, incandescent lamps such as those used on the Polish vessels are the most commonly used in the jig fishery. However, comparative tests with incandescent lamps and mercury vapor lamps indicate mercury lamps are about 2.5 times more efficient in attracting squid (Ogura and Nasumi, 1976). Mercury lamps are also more efficient in converting electric energy into light, are brighter and have a longer life, but the price is higher than for incandescent lamps.

Summary

Illex illecebrosus is very aggressive and exhibits an attractive taxis toward light which lends very well to night light jigging. Squid jigging is a fishing technique that is relatively simple in operation when compared with a trawl fishery. Since the jigging machine is fully automatic only a few men are required to run a dozen machines. Considering the rising cost of fuel, a jigging operation has favorable aspects. Indeed, the Polish vessels consumed only about half the fuel that would normally be consumed by a comparable vessel in a trawl fishery.

Good catches of squid were made from Cape Henlopen to Cape Cod along the continental slope. It would seem feasible that the catch rates of the Polish vessel could be substantially increased by the addition of more jig machines and a better lighting system, however.

Squid coming off the jigs are alive and in very good condition since the jig barbs put only a tiny hole in the tentacle. This leads to a high quality frozen product.

Light attraction jigging offers one more practical method to harvest squid. To outfit an existing vessel with squid jigging gear would be neither complicated nor costly as there are no specific vessel requirements that would necessitate any structural changes.

Acknowledgments

The authors wish to thank the captains and crew members of the Polish RV's *Murena* and *Wigry* for their generous hospitality and assistance during Douglas Long's stay aboard their vessels. We would also like to thank Kevin Heying of the Foreign Fisheries Inspector Program, National Marine Fisheries Service, for his assistance in collection of data, and to reviewers including William Gordon, James Medeiros, Bruce Freeman, David Kolator, and Bob Temple.

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Scanning Electron Microscopy of Squid, *Loligo pealei*: Raw, Cooked, and Frozen Mantle

W. STEVEN OTWELL and GEORGE G. GIDDINGS

ABSTRACT–Scanning electron microscopy (SEM) was used to investigate the tissue structure in raw, frozen, and cooked mantles from squid, Loligo pealei. *The mantle consists of five distinct layers of tissue: Outer lining, outer tunic, muscle fibers, inner tunic, and visceral lining. Each layer in the raw state is described. The freeze fracture techniques used to prepare samples for SEM viewing revealed tissue structural alterations caused by freezing the mantle to −29 °C. The same technique was used to observe thermal alterations caused by cooking the mantle to 100 °C. Loss of structural differentiation in the muscle fibers was the only discernible alteration caused by freezing, but cooking caused gross distortions in all mantle tissues.*

Introduction

The main body portion of a squid is the cone-shaped mantle which encloses the viscera. Early studies of squid mantle structure (Pierce, 1950; Tanaka, 1958; Wilson, 1960; and Young, 1938) are scant and incomplete, but outline the basic muscular arrangement: Bands of radial and circumferential muscle fibers arranged in an orthogonal manner and sandwiched between layers of connective tissue. With the advent of better transmission electron microscopic techniques, Ward and Wainwright (1972) gave a complete description of the entire mantle structure as it relates to locomotory function, and Moon and Hulbert (1975) define the fine structure of an individual squid muscle fiber. Structural analysis of squid tissue using scanning electron microscopy (SEM) has not been reported, nor has SEM been used to describe ultrastructural changes caused by cooking of invertebrate tissue.

The major intent of this study was to illustrate, with scanning electron photomicrographs, the ultrastructure of the tissue components of the mantle from squid, *Loligo pealei*. The structural description of the raw tissues is useful for interpretation of the locomotory function of the mantle, and for understanding the unique metabolic aspects of these tissues which function such that the squid is the fastest swimming marine invertebrate. In turn, the structural description of raw tissues provided a basis for comparative analysis of structural alterations caused by cooking and freezing.

SEM has been used successfully to demonstrate cooking alterations in beef tissues (Schaller and Powrie, 1972; Alexander and Fox, 1975; Cheng and Parrish, 1976; Jones et al., 1977), and the freezing alterations in crab (Giddings and Hill, 1976). Application of this microscopic technique, in combination with tests of physical strength and sensory textural analysis, could be used to evaluate food texture of squid as affected by cooking and freezing (Otwell and Hamann, 1979a, b).

Materials and Methods

Squid

Squid used in this study were harvested by commercial vessels fishing the North Carolina coast adjacent to Cape Hatteras. Average mantle length of squid used in this study was 14±4 cm (5.5±1.6 inches). Squid were packed on ice, transported to Raleigh, North Carolina, and cleaned for use (skin, head, and viscera removed) within 72 hours subsequent to harvest. It was assumed that at this time the squid musculature was in the post-rigor state. No squid was used which showed evidence of pigment "staining" on the mantle, which is an indication of mishandling and/or early spoilage (Takahashi, 1965). A portion of the squid was packed in 10 × 20 cm (3.9 × 7.8 inch) Whirl-pak[1] plastic bags, then frozen in a −29 °C walk-in freezer. Samples frozen for 20 days were used to determine the effects of freezing. Cooked samples consisted of mantles which had been boiled for 1 minute in distilled water. Water and samples were heated from room temperature to boiling at a warming rate of 5 °C/minute, and the temperature of the internal musculature and water were the same as determined by microthermoprobes.

SEM Procedure

Fresh, cooked, and frozen squid mantles were prepared by the same methodology prior to SEM evaluation. Thin slices (approximately 1 mm or 0.04 inch) of whole mantle cooled to 4 °C were cut with a razor blade in a specific manner according to muscle fiber direction. Cuts were made parallel and perpendicular to the circumferential fiber direction. All radial fibers were viewed in longitudinal section. Awareness of fiber orientation was essential for interpretation of photomicrographs (see Figure 1 for orientation).

[1]Mention of trade names, commercial products, or firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Sliced mantle was submerged in 5 percent glutaraldehyde (Electron Microscopy Science Company) in 1.M cacodylate-0.25M sucrose buffer for 16 hours fixation time. After the first 8 hours of fixation, submerged slices were cut into smaller lengths (4 mm or 0.16 inch) to assure fixative penetration. Glutaraldehyde was washed from the fixed tissue by two successive baths (12 hours each) of buffer containing half of the previous concentration of sucrose. Post-fixation of the tissue by exposure to osmium tetraoxide vapors was omitted from the procedure since it did not appreciably improve resolution. Fixed tissue was dehydrated by exchange in a graded ethanol series (15 minutes each in 30, 50, 70, 95, and 100 EtOH), and stored 24 hours in 100 percent ethanol.

Slight modifications of the freeze fracture procedure of Giddings and Hill (1976) were used to expose the surface for microscope viewing. Initially, the dehydrated tissue was cooled for 15 seconds in Freon 22 (chlorodifluoromethane, Dupont Company), then frozen by direct contact with liquid nitrogen. Frozen samples were fractured by a sharp blow to a single-edge razor blade positioned perpendicular to sample surface. Fracture orientation was selected with reference to fiber direction. Fractured pieces were slowly thawed in cool 100 percent ethanol, then solvent exchanged in a graded Freon 113 (trichlorotrifluorethane, Dupont Company) series. The procedure consisted of immersing 20 minutes each in 30, 50, 70, 95, and then placing in the 100 percent Freon 113. Immersion time in 100 percent Freon 113 did not exceed 12 hours. Preliminary tests indicated that prolonged exposure to Freon 113 (>12 hours) destroys fine tissue structures.

Samples packaged in Freon 113-impregnated envelopes of filter paper were dried in a Bomar SPC-50 critical point drier charged with Freon 13 (chlorotrifluoromethane, Dupont Company). Dried samples were mounted on aluminum stubs and coated with DAGS (colloidal graphite in isopropanol base; Ted Pella Company), then gold-coated for 5 minutes in a Polaron #5000 diode gold coater. Coated specimens were stored at room temperature in a vacuum desiccator until examined with an Etec Autoscan microscope operating in the linear mode at 20 kev, 12-8 working distance, 2.5 contrast, and 0 darkness. Both fractured and nonfractured surfaces were examined. Photomicrographs were taken with a Polaroid camera packed with type 55 Polaroid 5 × 5 Land film.

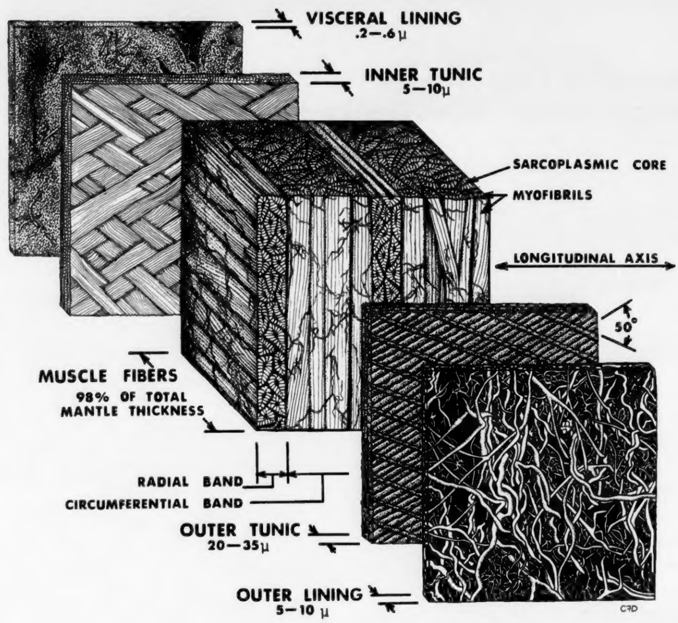


Figure 1.—Artist's rendition of the tissue composition in the mantle of squid, *Loligo pealei*. The view is an expanded cube cut from the entire thickness of the mantle. Skin has been removed from the outer lining, and the profuse sarcoplasmic tubular network typically surrounding the surface of the muscle fibers has been omitted to reveal muscle fiber structure. The longitudinal axis refers to the head to "tail" axis of the squid mantle.

Other Evaluations

Samples of different layers of mantle tissues were separated by sectioning with a freezing microtome. Moisture, crude protein, and hydroxyproline content was determined in three samples each from the separate layers, with at least three replications of each analysis per sample. Moisture and protein was determined by standard methods (AOAC, 1975). Protein was converted from nitrogen with multiplication by 6.25. Hydroxyproline content, as an indirect measure of collagen content, was determined by the colorimetric method of Woessner (1961).

Results and Discussion

Raw Squid

Figure 1 is an artist's rendition of the composite analysis of squid mantle ultrastructure. The figure is drawn slightly off scale to emphasize specific features of the various tissue components. The mantle is composed of five different layers of tissue. The muscle

fiber layer fills the bulk of the mantle thickness; the remaining layers account for approximately 2 percent of the total mantle thickness. The relation of mantle length (ML) to mean mantle thickness (MT) using cm units is: ML = (32.26 MT) −0.686 (Otwell, 1978). The terminology used to describe the various tissues in squid are consistent with that expressed by Ward and Wainwright (1972) and Moon and Hulbert (1975). The figures and descriptions provided are representatives from numerous hours of viewing numerous specimens and photographs.

Outer Lining

An outer lining of randomly ordered and sized fibers of connective tissue lies immediately below the skin (Fig. 2). This layer functions to attach the skin to the mantle. No previous report on squid mantle structure has identified this layer. This lining, with a thickness varying from 5 to 10μ, is composed of primary fibrils (0.1μ diameter) which aggregate into larger fibers (0.1-4.0μ). Bacteria was present on the outer lining in some specimens viewed. Immediately below this outside lining is an outer tunic of connective tissue (Fig. 3).

Outer Tunic

The outer tunic is comprised of layers of collagenous fibers (Ward and Wainwright, 1972) arranged in a mesh which is 20-35μ thick (Fig. 4). Fibers within one layer are parallel, running at a consistent angle (approximately 50°) to fibers in lower layers (Fig. 5). The angle is bisected by the longitudinal axis of the mantle. Individual fibers are 2-7μ thick, comprised of fibrils, 0.1±0.05μ diameter (Fig. 6). Lack of observable banding typical for collagen fibrils may be due to the high carbohydrate content reported for squid collagen, a mucopoly-saccaride (Hunt et al., 1970). The outer tunic appears identical to that described for squid by Ward and Wainwright (1972), but is distinctly different from the inner tunic which has been reported to have similar construction (Ward, 1970).

Inner Tunic and Visceral Lining

The inner tunic is the most difficult layer to observe because it is tightly covered by the nonfibrous visceral lining (Fig. 7). A fine point needle was used to puncture this lining to expose portions of the inner tunic. The inner tunic is connective tissue comprised of 1-5μ diameter fibrous aggregates of 0.1μ diameter fibrils. Fibrous aggregates are loosely bound and interwoven in a 5-10μ thick mesh. A few samples of the 0.2-0.6μ thick visceral lining is laden with pockets of bacteria (Fig. 8).

Although the construction of the outer and inner tunics appears distinctly different, their chemical composition is similar. Both tunics are stained in the same manner by Masson's Trichrome stain, or Verhoeffs elastic stain (stains: Manual of Histologic Staining Methods, AFIP, 1968), and contain hydroxyproline (Table 1). The tunics were shaved free of the mantle with a freezing microtome prior to hydroxyproline determinations. Higher hydroxyproline content in the outer tunic could be evidence for a difference in molecular construction. Hydroxyproline from the muscular layer substantiates the report by Ward and Wainwright (1972) of intramuscular collagenous fibers.

Muscle Fibers

Muscle fibers are arranged in rows of orthogonal bands (Fig. 1). Radial bands (10-15μ thick) are comprised of fibers which connect the two tunics of connective tissue (Fig. 9). Wider circumferential bands (100-200μ; $\bar{x}$ = 130μ thick) are comprised of fibers running about the entire circumference of the mantle cone. Length of individual circumferential muscle fibers was not determined.

Fiber anatomy (Fig. 10) is the same regardless of orientation. Average fiber diameter is 3.5±2.5μ. Each fiber has a central sarcoplasmic core which houses numerous mitochondria and at least one nucleus. The core is formed by a periphery of myofibrils. Due to the small fiber size, the SEM was unable to detect myofilaments or striations, typically seen with scanning electron microscopes in the larger (50-100μ diameter) mammalian fibers, (Cheng and Parrish, 1976; Jones et al., 1977).

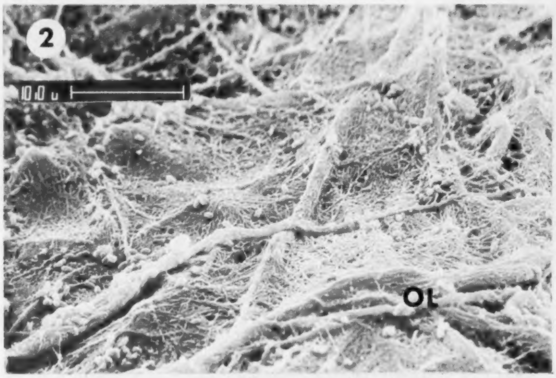
The tendency for fibers to fracture obliquely (Fig. 10) is consistent with the view that squid muscle is truly obliquely striated (Ward and Wainwright, 1972; Moon and Hulbert, 1975), and that the weak lines for fracture are the dense "Z-bodies," similar to "Z-line" fractures reported by Jones et al. (1977) and Schaller and Powrie (1972). All fibers are surrounded by the profuse sarcotubular network noted by Moon and Hulbert (1975).

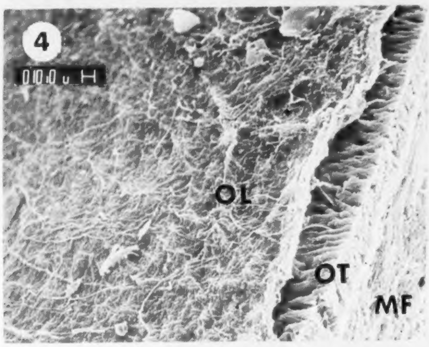
Frozen Squid

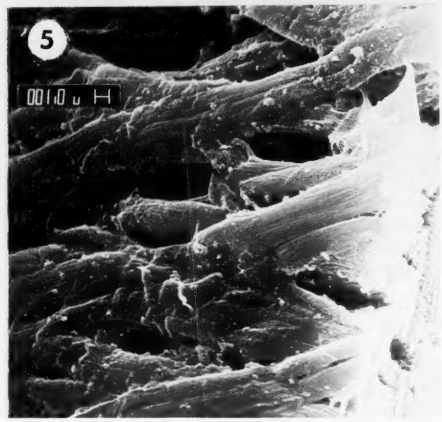
Fracture patterns, larger interfiber spacing, and diminished fine structure of the muscle fibers were the only discernible alterations in mantle tissue caused by freezing (Fig. 11 A, B). Previously frozen fibers fractured at right angles to the fiber direction, rather than obliquely as with fresh fibers. These results are most likely due to freeze alteration of myofibrillar proteins which has been detected in other species by quantitative changes in protein extractions (Powrie, 1973), and with transmission electron microscopy

Table 1.—Percent protein and hydroxyproline in separate layers of the squid mantle. Standard deviation cited (±) was computed across three separate samples per tissue, and at least three replications of each analysis.

Tissue	Percent protein	Percent hydroxyproline	Percent of total mantle thickness
Outer lining and outer tunic	17.06 ± 0.30	0.270 ± 0.06	0.5-1.5
Muscle fibers	16.88 ± 0.30	0.082 ± 0.01	
Inner tunic and visceral lining	16.04 ± 0.48	0.107 ± 0.05	0.1-0.5







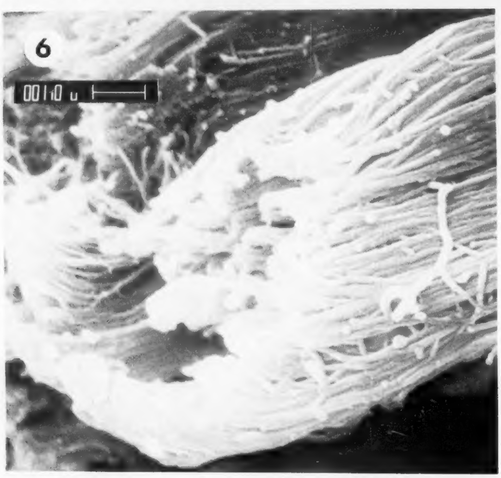


Figure 2.—Angled view of the outer lining: Note bacteria. Figure 3.—Punctured outer lining revealing the ordered mesh construction of the outer tunic of connective tissue. Figure 4.—Outer tunic covered by the outer lining. Figure 5.—Close view of the interwoven fibers in the outer tunic. Figure 6.—Fibril arrangement in an individual collagen fiber from the outer tunic.

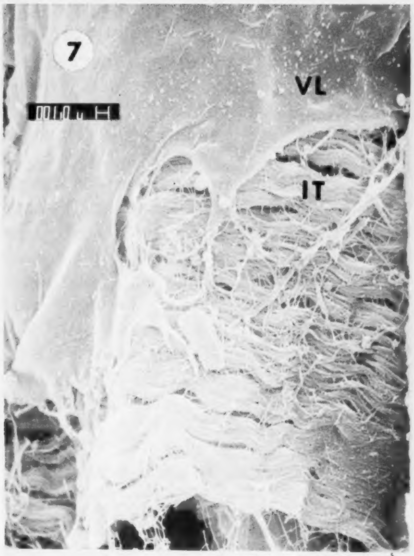


Figure 7.—Punctured visceral lining (VL) reveals the arrangement of fibers in the inner tunic (IT).

Figure 8.—Bacterial growth on the surface of the visceral lining.

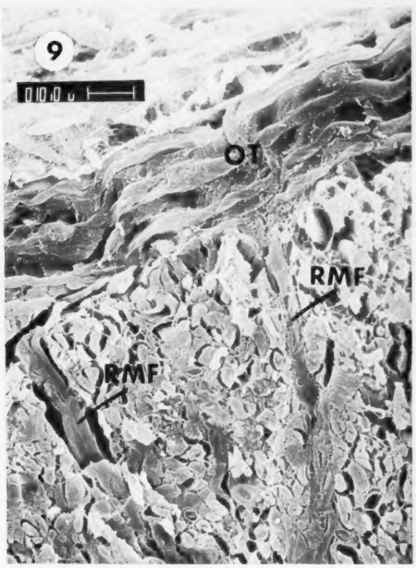


Figure 9.—Intersection of radial muscle fibers (RMF) with the multilayered outer tunic (OT). The RMF form a Y-shaped intersection.

Figure 10.—Fractured surface of circumferential muscle fibers (CMF). Note the profuse sarcoplasmic network (S), myofibrils (M), and sarcoplasmic core (SC).

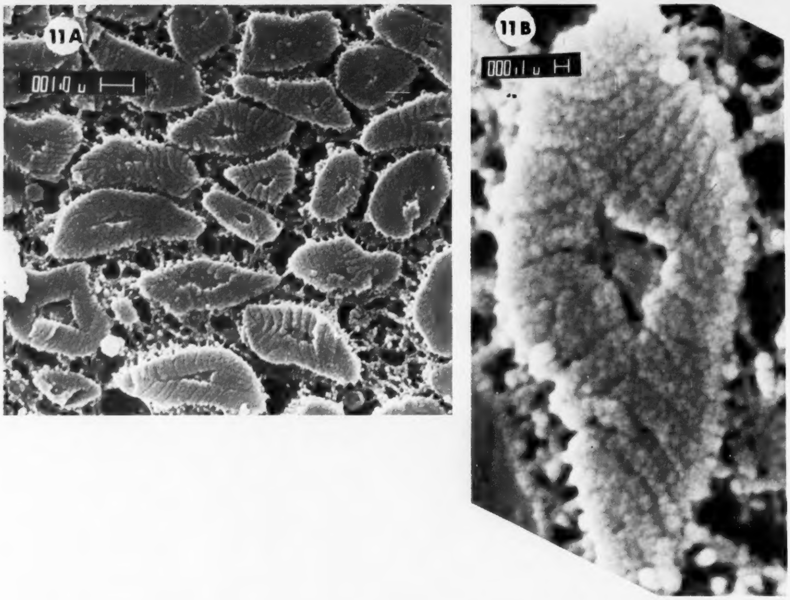


Figure 11A, B.—Muscle fibers frozen for 20 days at $-29\,^{\circ}\mathrm{C}$.

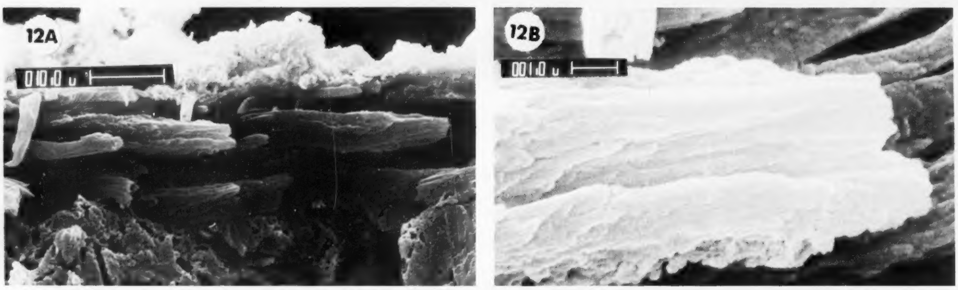


Figure 12A, B.—Heat denaturation of the outer lining and outer tunic. In A, tunic fibers still remain intact; in B, fibrils have "melted" into a solid mass.

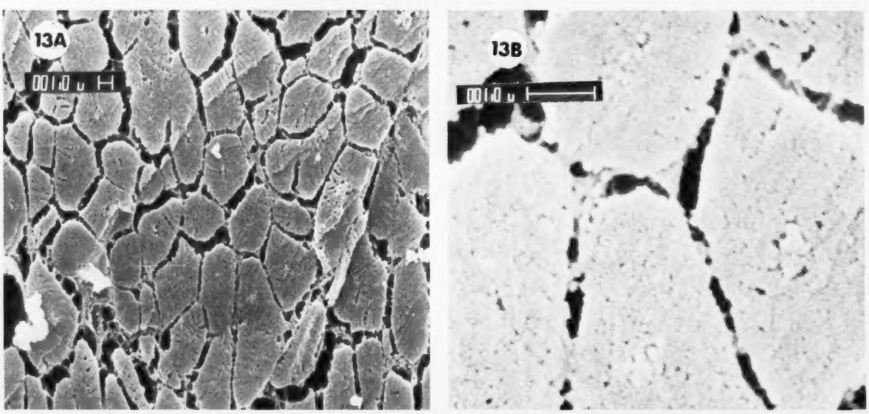


Figure 13A, B.—Heat denatured (100 °C) muscle fibers. Sarcoplasmic core is shrunken and filled with heat-globularized proteins, and myofibril distinction is poor.

(Tanaka, 1965; Jarenbäck and Liljemark, 1975a, b).

It is generally thought that both slow freezing and duration of frozen storage results in fiber dehydration and compression due to growth of extracellular ice crystals. Consequently, this mode of frozen storage causes partial dehydration of intramyofibrillar spaces allowing the myofilaments to become more compact, hardened, and possibly crosslinked. Homogeneous hardening of the myofibrils caused by freezing would tend to decrease the probability of fracture along dense "Z-bodies," and myofibrillar crosslinking could decrease fiber resolution.

Cooked Squid

Photomicrographs of squid mantle cooked in boiling water for 1 minute showed gross distortions of all mantle tissues. The visceral lining, the most heat labile tissue completely disintegrated. Tunics of connective tissue showed signs of "melting" and "gelatinization." The outer tunic fibrils had congealed, and the fibers were beginning to "melt" into a solid gelatinous mass (compare Figures 4, 5, and 6 with 12A and 12B, respectively). The outer lining was only partially disintegrated.

Cooked muscle fibers remained intact but appear hardened and dehydrated (Fig. 13A, B). The central sarcoplasmic cores were shrunken and filled with globular structures identified as heat coagulated proteins. Only slight outlines of myofibril units remained. The muscle bands were more densely packed and the mantle had lost 37 percent of the original wet weight (Table 2).

Table 2.—Protein and moisture content of fresh, frozen, and cooked squid mantle.

Mantle	Percent protein	Percent moisture	Cook weight loss
Fresh, raw	16.59 ± 0.21	81.26 ± 0.14	
Frozen (−29°C) 29 days	16.08 ± 0.32	81.48 ± 0.06	
Cooked (100°C) one minute	19.93 ± 0.30	77.51 ± 0.08	37%

Conclusions

Squid mantle consists of five distinct layers of tissue. The dominant layer consists of orthogonal bands of muscle fibers, which are sandwiched between two tunics of connective tissue. Ultrastructure of each layer as revealed by SEM agrees with previous TEM descriptions of squid mantles. SEM revealed structural alterations in squid mantle which had been frozen or cooked. Freezing caused discernible structural alterations in muscle fibers which suggest dehydration and homogenous hardening of the fibers. Cooking caused gross distortions of all mantle tissue. Heat coagulation of proteins and gelatination of connective tissues were obvious. Diminished structural definition and size of muscle fibers suggested fiber hardening and dehydration. Thus, it appears feasible that scanning electron microscopy can be used to subjectively evaluate changes caused by heating and freezing squid mantle. The changes observed suggest rapid freezing to minimize ice crystal formation and subsequent moisture loss during thaw is a better method of freezing squid. Cooking methods for squid should avoid excessive dehydration of the tissues.

Acknowledgments

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The Quality of Squid Held in Chilled Seawater Versus Conventional Shipboard Handling

VINCENT G. AMPOLA

Introduction

The principle of using refrigerated seawater for the bulk holding of fish aboard vessels is not a new concept. One of the earliest records of this application is found in a U.S. patent issued in 1919 to J. M. Larsen for a method of holding freshly caught fish in clear filtered seawater at about 0 °C (32 °F) or lower (Peters et al., 1965).

Some reasons for using seawater cooled either by mechanical means (refrigerated = RSW) or by ice (chilled seawater = CSW) are to cool the fresh fish down to a temperature of 0 °C (32 °F) or lower as quickly as possible since spoilage rates are directly related to storage temperature, to disperse spoilage inducing products by the washing effect of the seawater, to eliminate crushing and ice damage, and also for ease of loading and unloading (Roach, 1965).

Chilled seawater, using ice as the coolant, has recently been used in the bulk holding of herring (Hewitt and McDonald, 1972; Hulme and Baker, 1977), squid (Learson and Ampola, 1977), and mixed species of fish (Baker and Hulme, 1977).

The two objectives of this work were to compare the fresh shelf life of squid held in CSW after being caught versus squid held in the traditional manner—iced down in boxes or iced down in pens aboard ship, and to compare the organoleptic quality of squid frozen at sea immediately after capture against squid held in CSW, in boxes, and in pens aboard the boat and then frozen 1 to 2 days after capture.

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Procedure at Sea

The fishing vessel used for catching the squid, *Loligo pealei*, used in this experiment had an insulated fish hold capable of holding 15 tons of seawater, ice, and squid. The hold was divided into six pens, five to hold squid, and one pen reserved as working space for loading and unloading squid. A schematic of the hold layout is shown in Figure 1.

Before each trip, Pen C was charged with about 3 tons of crushed ice. Pen boards dividing the insulated hold had openings covered with perforated stainless steel mesh which allowed for the free circulation of chilled seawater which was pumped from the bottom of Pen F into the top of each of the other pens.

Squid Held in CSW

In all, three separate trips were made to catch squid. Squid caught on the earliest tow of each trip were always placed in Pen A, and the squid/ice/seawater ratio was adjusted as close to 3:1:1 as possible according to the procedure of Baker and Hulme (1977). This mixture provided a workable slush into which the freshly caught squid were submerged. During each trip, the top and bottom temperatures of all the pens were monitored by a Cole Palmer[1] electronic thermometer.

Boxed Squid

A shovelful of ice was placed on the bottom of a 45-kg (100-pound) capacity wooden fish box, about 35 kg (80 pounds) of squid were added, together with some additional ice, another shovelful of ice was placed on top of the mass, and the cover was nailed on. The boxes were stored in an aft compartment of the boat.

Penned Squid

Squid were mixed with ice in approximately a 3:1 squid/ice ratio, and then shoveled into pens with pen boards holding the mass. The height of the mixture was about 1.2 m (4 feet). These pens were located in another area of the boat.

Squid Frozen at Sea

On the first trip, 12 cartons, each containing 2.3 kg (5 pounds) of freshly caught squid were frozen in dry ice.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

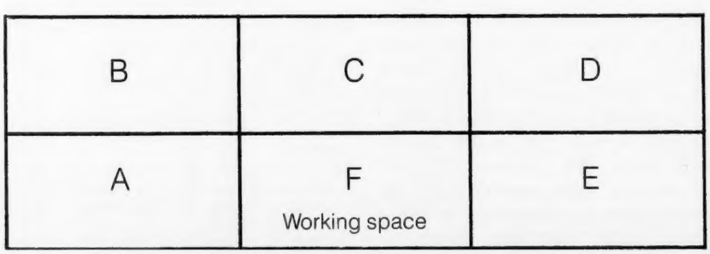

Figure 1.—Chilled seawater hold aboard the vessel.

These samples were used as frozen-at-sea controls for subsequent organoleptic tests.

Procedure Ashore

After each of three trips, squid from the CSW Pen A and some boxed and penned squid were deiced, weighed, and repacked with ice into 22.7-kg (50-pound) cardboard fish boxes. These containers plus the frozen-at-sea squid were transported from Pt. Judith, R.I., to the Gloucester Laboratory where the iced squid were placed in a refrigerated room held at 1.1 °C (34 °F). The frozen sample was stored at −20.6 °C (−5 °F). Some squid taken from the CSW tank and some boxed and penned squid were packed into 2.3-kg (5-pound) cartons, plate frozen at −40 °C (−40 °F) overnight and then stored at −20.6 °C (−5 °F). The rest of the squid were kept in ice (at about a 2:1 squid/ice ratio) in their containers. Ice loss due to melting was replenished as needed.

Quality Determination

Fresh

Squid held in CSW, in boxes and in pens aboard ship, and then held in ice at the laboratory were evaluated daily for appearance and odor by a 12-member panel experienced in the quality evaluation of marine products. The raw squid were presented to the panel whole and cut open. They rated them on a 5-point scale where 5 = Very Good, 4 = Good, 3 = Fair, 2 = Borderline, and 1 = Poor. When the average score of a sample was 2.6 or above for either appearance or odor, the squid were considered acceptable. An average score of 2.5 or less given for either appearance or odor was cause to reject the squid as unacceptable and marked the end of shelf life for that sample.

Frozen

For this procedure, frozen squid from each treatment lot were thawed by immersion in cool tap water. Some of the squid were cut open; some were left whole, and they were presented to the evaluation panel. The 5-point scale was used for evaluating their appearance and odor. After this procedure, the squid were cleaned; the mantles were diced and then boiled in unsalted water until tender. Several pieces of squid from each lot plus some of the cook water were presented to the panelists who rated them for appearance, odor, flavor, and texture on a 9-point hedonic scale. Organoleptic scores for each of these sensory attributes were analyzed for significant difference by analyses of variance.

Table 1.—Sensory scores[1] and shelf life of raw squid held three different ways before landing and stored in ice at 0.6°-1.1°C (33°-34°F).

Total age of squid (days)	CSW		Boxed		Penned	
	App.	Odor	App.	Odor	App.	Odor
Trip 1						
2	4.0	5.0	4.0	5.0	4.0	5.0
3	4.5	4.5	4.5	4.5	4.5	4.5
4	4.0	4.0	4.0	4.0	3.0	4.0
5	4.3	4.2	3.9	3.8	4.0	3.9
6	4.3	4.3	3.7	3.3	4.0	3.7
7	4.0	4.1	4.1	3.8	3.8	3.8
8	3.7	4.1	3.7	3.8	3.3	[2]3.7
10	4.0	3.0	4.0	[2]3.0	3.0	1.0
11	3.8	[2]3.2	3.3	2.3		
12	1.8	1.2				
Trip 2						
3	4.8	4.8	4.8	4.8	4.7	4.5
4	4.5	4.6	4.6	4.5	4.5	4.6
5	4.0	3.9	4.3	4.3	4.3	4.3
6	4.2	4.3	4.2	4.1	3.9	3.8
8	3.0	4.0	3.0	[2]4.0	3.0	4.0
9	3.3	3.1	3.3	2.3	3.3	3.2
10	3.3	[2]2.8			3.2	2.8
11	3.0	1.5			3.0	[2]2.8
12					2.6	1.4
Trip 3						
3	4.4	4.3	4.5	4.5	4.5	4.5
4	4.4	4.6	4.3	4.5	4.3	4.5
5	4.3	4.4	4.3	4.2	4.3	4.4
8	4.1	4.0	3.7	3.9	4.1	4.1
9	3.6	3.0	3.6	[2]3.9	3.5	3.8
10	3.3	[2]2.9	3.1	1.9	3.0	[2]2.8
11	2.0	1.3			2.5	1.8

[1]A 5-point scale was used where 5 = Excellent, 4 = Very Good, 3 = Good, 2 = Borderline, and 1 = Poor.
[2]End of acceptable shelf life.

Organoleptic Results

Iced Squid

Sensory scores for appearance and odor of raw squid obtained from the CSW tank, boxes, and the pans of the vessel and stored in ice at the laboratory are shown in Table 1.

There was little difference in the iced shelf life of squid held in CSW, in boxes, and in pens. The total shelf life of squid held in CSW aboard the boat for 1-2 days and then in ice in the laboratory was 11, 10, and 10 days. Iced squid held in boxes had a total shelf life of 10, 8, and 9 days. The penned squid held in ice had a total shelf life of 8, 11, and 10 days.

Table 2.—Organoleptic results of squid held at −20.6°C (−5°F) for 9 months.

Age of squid (months)		Raw evaluation thawed		Cooked evaluation[1]
		App.	Odor	
1	Frozen at sea	4.6	[2]4.3	[3]7.1
	CSW	4.4	4.3	6.9
	Boxed	4.3	4.3	7.1
	Penned	4.4	4.5	7.3
2	Frozen at sea	4.5	4.3	7.7
	CSW	4.3	4.3	7.5
	Boxed	4.5	4.7	7.3
	Penned	4.3	4.3	7.4
3	Frozen at sea	4.6	4.5	7.5
	CSW	4.1	4.3	7.4
	Boxed	4.3	4.4	7.2
	Penned	4.6	4.6	7.8
4	Frozen at sea	4.8	4.6	7.6
	CSW	4.5	4.5	7.5
	Boxed	4.3	4.4	7.1
	Penned	[4]3.9	4.5	7.2
5	Frozen at sea	4.8	4.7	7.2
	CSW	4.1	4.2	7.3
	Boxed	4.3	4.5	7.2
	Penned	4.3	4.8	7.2
6	Frozen at sea	4.7	4.6	7.0
	CSW	4.3	4.4	7.3
	Boxed	4.3	4.3	7.0
	Penned	4.1	4.5	7.2
8	Frozen at sea	4.5	4.8	7.8
	CSW	4.0	4.1	7.6
	Boxed	4.2	4.3	7.6
	Penned	3.7	3.9	7.7
9	Frozen at sea	4.6	4.3	7.4
	CSW	4.1	4.0	7.4
	Boxed	4.3	4.3	7.4
	Penned	4.1	4.1	7.4

[1]Overall average of appearance, odor, flavor, and texture.
[2]Evaluated on the 5-point scale used in Table 1.
[3]A 9-point scale was used where 9 = Excellent, 8 = Very Good, 7 = Good, 6 = Fair, 5 = Borderline, 4 = Slightly Poor, 3 = Poor, 2 = Very Poor, and 1 = Inedible.
[4]P = 0.05 percent from the frozen-at-sea sample.

Frozen

The sensory data on the raw and cooked evaluation for squid obtained from the CSW tank, the boxes, and pens, and then held at −20.6 °C (−5 °F) were compared with squid frozen at sea immediately after capture. These results are shown in Table 2.

Except for a significant difference in the appearance of the penned squid and the frozen-at-sea control at 4 months,

all samples evaluated in the raw state remained highly acceptable over the 9-month storage period.

When tested cooked, there were no significant differences in appearance, odor, flavor, or texture between the frozen-at-sea samples and squid held in CSW, in boxes, or pens aboard ship and then frozen for 9 months.

Discussion

There was a slight difference between the shelf life of squid held in CSW and those iced down in boxes and in pens after capture. Squid held in CSW for 1-2 days and then in ice had an average shelf life for the three determinations of 10.3 days, while the average shelf life of boxed squid was 9 days, and the penned squid, 9.7 days. In all cases, the squid were rejected primarily on the basis of odor rather than appearance. The odor of all samples during iced storage deteriorated rather slowly. As time progressed, the panelists commented on lack of fresh odor, no odor, and finally, flat sour or slightly ammoniacal odors upon rejection.

There was, however, a great difference in appearance between the CSW squid and the boxed and penned squid when seen at dockside. Squid held in CSW were of unusually good appearance with very few bruises, skin tears, and no crush marks. Some of them were still in rigor; the eyes were bright, and the tentacles of most of them were tightly curled. This may have been due to the lower temperature in the CSW tank—the average temperature of the ice/seawater slush averaged -1.4°C (29.4°F) for the three trips. The temperature of the squid held in boxes and pens averaged about 0.6°C (33°F). Boxed squid exhibited bruise marks and showed the effects of compression, while those held in pens showed both of these characteristics and also some inky discoloration.

The organoleptic data obtained on frozen squid tested raw and cooked (Table 2) show that the products were of excellent quality over the 9-month storage period. Squid frozen immediately after capture differed in color from squid frozen at the laboratory. During frozen storage and even after thawing, the pigmentation of the frozen-at-sea squid was a vivid reddish purple rather than the purplish gray of the other samples. The skin chromatophores were sharply defined and slightly larger than normal. This coloration manifested itself in higher appearance scores received when they were examined in the raw, thawed state; however, when boiled, this difference was not evident. The frozen-at-sea squid were also firmer and slightly more rigid than the other samples after thawing. The other samples may have been lightened by the bleaching effect of the salt water or ice.

Conclusion

Holding freshly caught squid in CSW for 1 or 2 days after capture was not long enough to appreciably extend its iced shelf life over the other two methods. There are, however, advantages for holding squid in CSW. One is that the initial appearance of these squid was considerably better than the boxed or penned samples. Another advantage is the elimination of the labor intensive practice of icing them down in boxes or pens. Squid placed in CSW are rapidly chilled to about -1.7° to -1.1°C (29° to 30°F). They are separated from intimate contact with one another and to ice by floating in a fluid medium. They could be pumped from the hold, thus making off-loading less labor intensive and less damaging to the squid. Squid frozen at sea were better in appearance and in firmness than those held in CSW, boxes, or in pens prior to freezing.

There may be disadvantages in storing squid in CSW. According to Roach (1965) and Merritt (1969), prolonged immersion (over 7 days) of ungutted fish in CSW has led to undesirable changes in appearance, changes in the salt composition of the flesh, and leaching out of soluble components, including protein.

In a previous experiment, Learson and Ampola (1977) held freshly caught *Illex illecebrosus* in CSW, in boxes, and in pens, and found that the shelf life of the squid held continuously in CSW was 7.3 days as compared with 6.0 and 5.0 days, respectively, for the boxed and penned squid.

Although these results indicate that there is an advantage to holding freshly caught squid in CSW, the appearance of the frozen-at-sea samples would seem to indicate that packaging and freezing of freshly caught squid at sea, although not practical for small boats, would be of definite advantage, especially if they were consigned for sale in foreign markets.

Acknowledgment

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Development of a Squid Skinning and Eviscerating System

R. PAUL SINGH and DANIEL E. BROWN

Introduction

Despite its excellent food value, a North American market for squid is virtually non-existent. The appearance of whole squid is unappetizing to many in the market place despite its relatively low retail price ($0.69 to $0.99/pound). The average consumer does not know how to clean or prepare whole squid for consumption. Seafood restaurants serving squid find the demand low and the hand-cleaning costs high. Hand cleaning adds $1.50 to $2.00/pound to the price of squid for the restauranteur. Prepared foods made from cleaned squid meat have been well received in preliminary tests (Berk, 1974), and this shows that there is a potential market for squid in this country.

One species of squid abounds off the coast of California, *Loligo opalescens* Berry (California Market Squid). Current methods for processing squid by the California fishing industry involve canning whole squid for foreign markets and freezing whole squid for both domestic and foreign consumption. The high costs of manual cleaning limits its use to small-scale special-order vendors. Cleaning involves removing the head, eyes, skin, viscera, ink sac, and backbone from the mantle. This leaves a white flesh cone which can be split into a fillet. The tentacles are saved intact for human consumption. Currently, there are no mechanical systems available commercially for cleaning squid. The development of an industrial-scale machine for economical cleaning of squid could have a revolutionary effect on this industry. The overall goal of the research reported in this paper was to develop a completely automated squid processing system.

Design Considerations

Squid and its various components are shown in Figure 1. The body wall thickness is 3-5 mm (0.1-0.2 inch). The cleaned body, called a mantle, resembles a hollow, flexible cone. This conical shape is used in the alignment, ducting, skinning, and eviscerating processes of the machine.

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Orientation and Alignment

The basic data needed to design the orientation and alignment component was obtained by Brooks and Singh (1979). The coefficient of sliding friction of the squid tentacles was found to be higher than that of the mantle. This fact allowed the squid to rotate into the desired alignment to slide mantle-first into the machine. Tests with the machine indicated that the squid oriented within their own length. This operation is shown in a schematic in Figure 2.

The squid slid into an alignment trough to be positioned for separation of tentacles and was also cut near the body-cavity opening for further processing (Fig. 2). Cutting through the squid body, 6.4 mm (0.25 inch) from this body-cavity opening, greatly facilitated skinning, evisceration, and backbone removal. The strongest attachment points for the skin, viscera, and backbone were located by Brooks (1978) on the ring of flesh severed from the body cone with the head/eye mass (Fig. 1).

The alignment trough, 19.1 mm (0.75 inch) wide, accepted the squid from the orientation slide in any axial position and supported it so that the

ABSTRACT–A squid skinning and eviscerating machine was designed for California market squid, Loligo opalescens. *Various operations such as orientation, cutting, skinning, and evisceration were completely automated. Solenoid valves were used to operate the various components for the cleaning operations. The output from the machine was a cleaned white mantle in tubular shape and tentacles. The machine operates with a low consumption of water. The pilot-scale machine cleaned squid at a rate of four squid per minute. Industrial scale-up for processing 10 tons of squid per 8-hour shift is explored in the paper.*

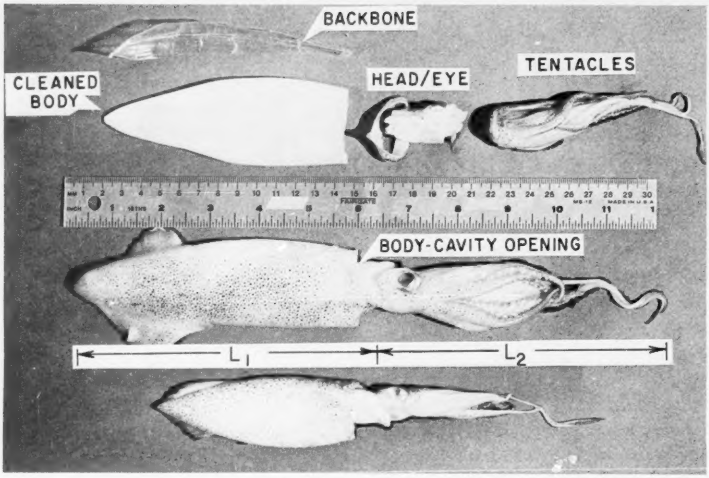

Figure 1.—Cleaned squid parts above, whole squid below.

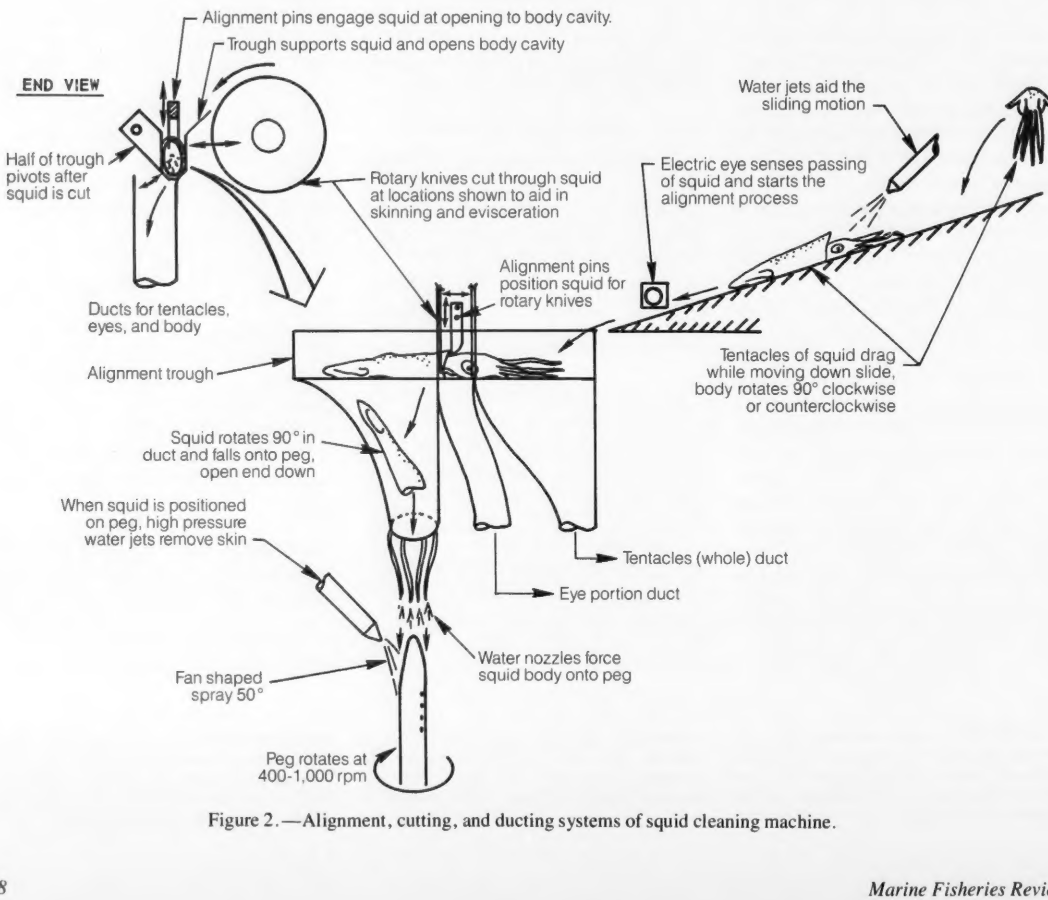

Figure 2.—Alignment, cutting, and ducting systems of squid cleaning machine.

body-cavity opening protruded above the rest of the squid. Alignment pins engaged the protruding lip of the body-cavity opening, as shown in Figure 2, and pushed the squid in the trough forward until it was correctly positioned opposite the rotary knives.

The tip speed of the rotary knives was 5.6 m/second (18 feet/second). The squid were cut quickly and cleanly. Since the body-cavity opening was used as the alignment point, the body length, L_1 (Fig. 1), and the tentacle/head length, L_2, may vary without affecting the alignment efficiency. The length L_1 may vary from 88.9 mm (3.5 inches) to 170.2 mm (6.7 inches) and L_2 may vary by the same extremes (Fig. 1). The size variance and size ratio of tentacles to mantle was therefore eliminated as a factor in aligning and preparing squid for processing.

Ducting of Squid

The elongated, conical shape of the squid mantle facilitated its ducting from the alignment trough to the skinning/evisceration peg. The mantle was firm enough to remain oriented longitudinally in a close-fitting duct, 38 mm (1.5 inches) to 51 mm (2.0 inches) in diameter, and could be transported by gravity or with the aid of moving water over any distance required.

Skinning Process

The hollow conical mantle was ducted onto a rotating peg, as shown in Figures 2 and 3. The viscera, attached to the dorsal side of the mantle interior, was displaced to one side as the mantle slid onto the peg. The squid is shown in place in Figures 4 and 5. The mantle assumed the rotation of the peg, 400-1,000 rpm, and rotated along its major axis below the water jets used for skinning. The longer the mantle, the more of the peg was covered. Again, the size and length variation problems were avoided using this holding technique. The body-cavity opening was kept open and circular as it was ducted onto the peg by a flexible-tube water-jet funnel (Fig. 2, 3). The tubes of the funnel supported all sides of the flexible mantle wall as it passed through, keeping it circular. Jets of water issued from these tubes along the length of the body, accelerating the conical mantle onto the peg.

One nozzle, producing a fan-shaped water spray, was used to skin the mantle. The mantle draped over and supported by the peg, received an even blast of water as it rotated under the water nozzle. The fins were sheared from the mantle by the skinning nozzle and were propelled out and away from the rotating peg. The fins dragged much of the skin off with them because of the skin's firm attachment at their edges. The remainder of the skin was peeled down the length of the mantle by the downward blast from the water nozzle.

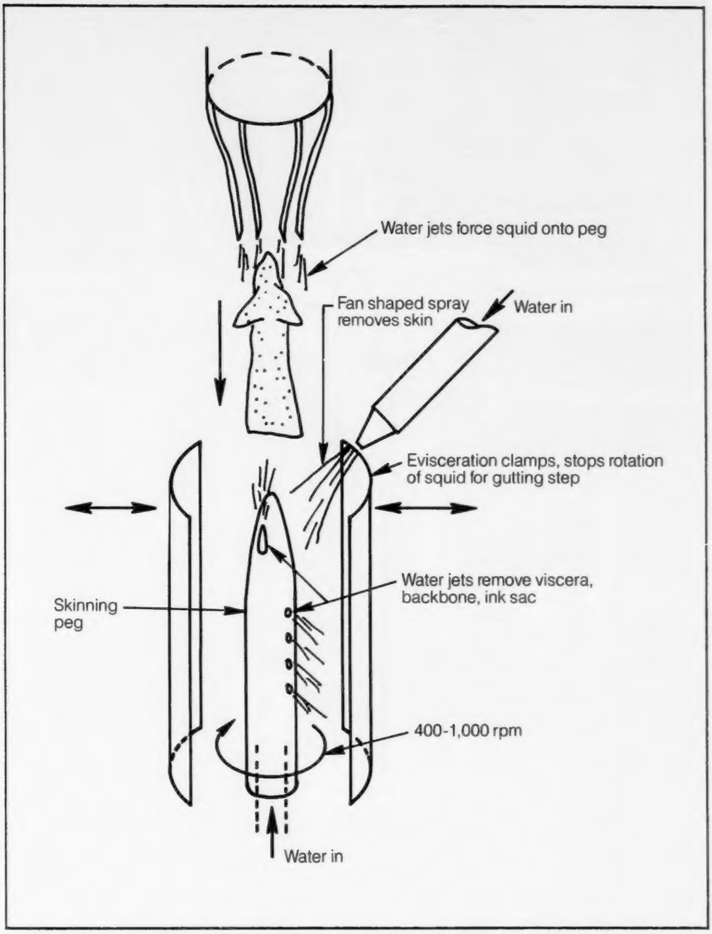

Figure 3.—Squid skinning and evisceration system.

Evisceration and Pen Removal

The remaining cleaning operations namely, evisceration, ink sac removal, and backbone (pen) removal were accomplished by water jets provided inside the rotating peg (Fig. 3) over

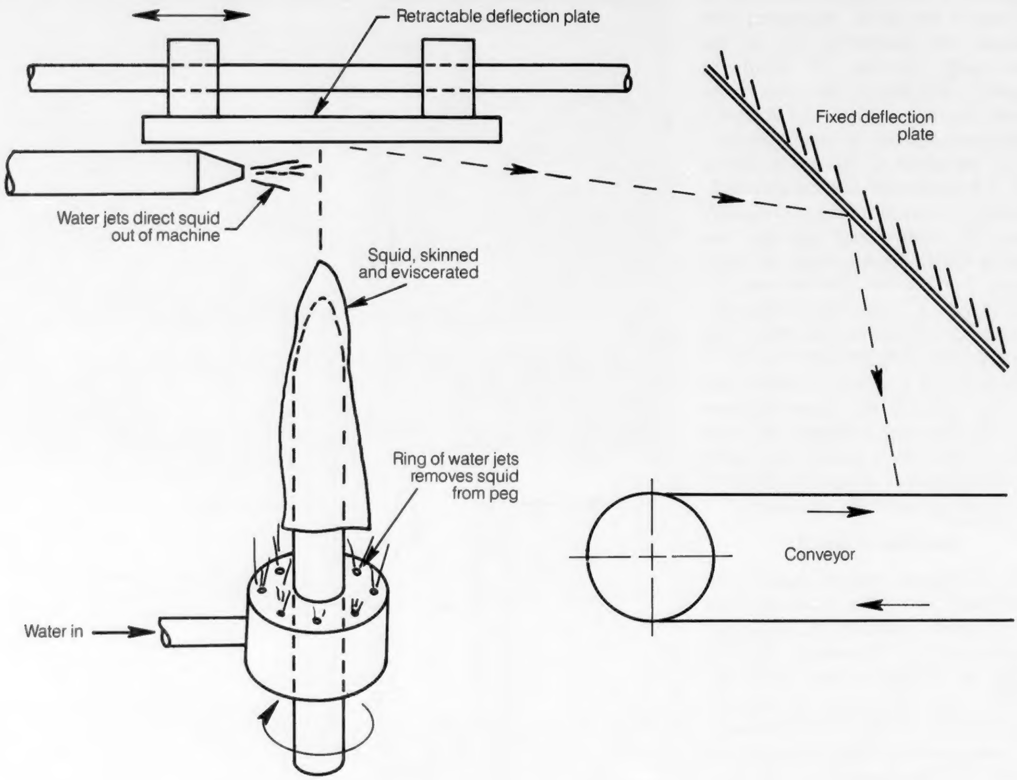

Figure 4.—System to remove cleaned squid from machine.

which the mantle was still draped. A pair of clamps closely matching the conically shaped mantle exterior engaged the squid body, stopping its rotation relative to the peg, and supported it for evisceration. The rotating peg's water jets swept past the interior of the mantle, giving an even 360° coverage, shearing off the viscera and membranes holding the backbone. The evisceration clamps kept the mantle from blowing up like a balloon. The viscera were flushed out the open bottom of the mantle. The viscera, skin, and backbones were collected in a large pan under the machine. The water was drained off.

Removal of Squid From Machine

The cleaned squid mantle was then propelled off the peg and out of the machine by a ring of water jets at the base of the skinning/evisceration peg (Fig. 4). A deflection plate was moved into position between the skinning peg and water-jet funnel. Water nozzles directed the flight of the cleaned squid mantles out of the machine.

The tentacles and eye/head portion of the squid, having been severed from the body by the rotary knives, were ducted out of the machine for further processing (Fig. 2). No attempt was made to skin the tentacles or to remove the beak from them. The tentacles are nevertheless highly desirable for human consumption.

Allied Design Features

Half of the trough, which supported the squid for the cutting process, pivoted to allow the three parts of the squid—mantle, head/eyes, and tentacles—to fall into their respective ducts, as shown in Figure 2. Water jets aided in cleaning the trough of squid parts. The contour of the duct into which the body portion falls (Fig. 2) ensured that the squid was ducted to and inserted on the skinning peg properly, body-cavity opening first.

The water nozzle used in skinning produced a thin fan-shaped high-velocity cutting sheet. The operation pressure used was 60-80 psi. Water supplied to the nozzles and other water jets was controlled by solenoid valves

mounted on a manifold. The manifold was pressurized by a positive displacement roller pump.

The water jets used in evisceration cut in the support peg are visible in Figure 3. The peg was hollow and the water supply to it was also controlled by a solenoid valve. A rotary seal at its base allowed for its rotation.

The operation of the pilot-scale squid processing machine (Fig. 6) was fully automatic. The control system for the various functions performed by the machine was activated by an electric eye. It sensed the squid entering the machine via the orientation slide (Fig. 2). It set in motion a rotary stepping switch. This activated the solenoid valves supplying water to the nozzles, or the solenoids, providing linear motion to devices like the alignment pins or evisceration clamps. Fifteen seconds was required to run through the sequence producing a cleaned squid. Another squid was then inserted into the machine initiating the sequence again.

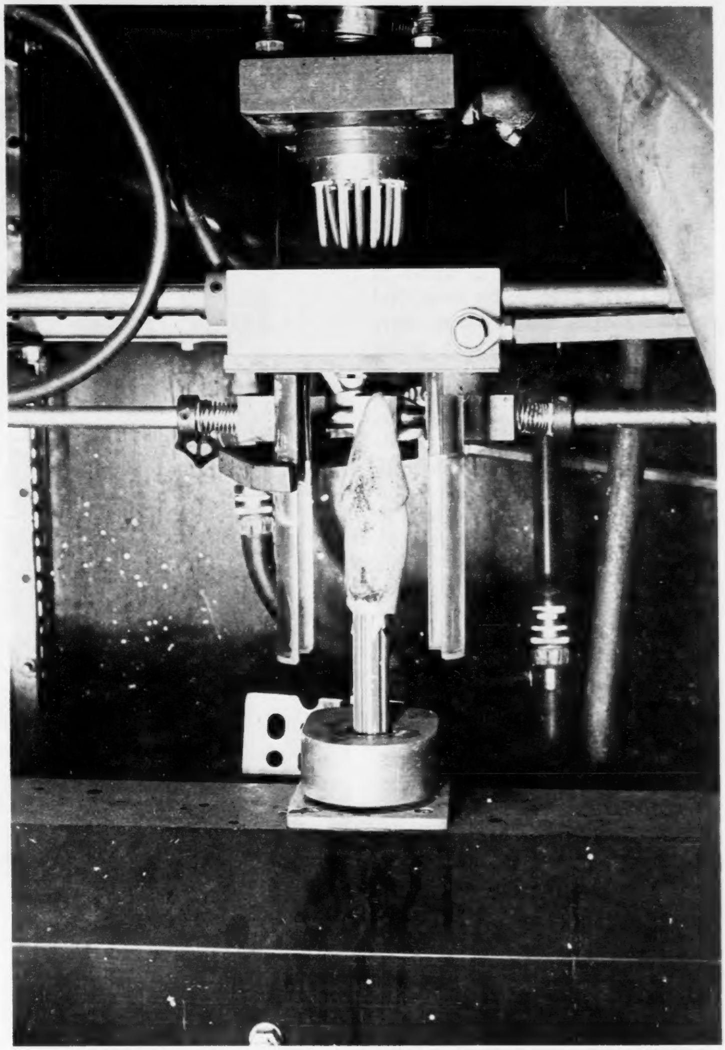

Figure 5.—Squid mantle in place on skinning and evisceration peg.

Performance Trials

The pilot-scale squid processing machine has been tested extensively to obtain information on its performance. Two samples of squid were used. The first was obtained frozen in 1.5-kg (3.3-pound) boxes from Meredith Fish Co.[1], Sacramento, Calif. The second sample was obtained 24 hours after it was caught in the ocean from Sea Products Co., Moss Landing, Calif. This sample had been placed in cold storage in 10-kg (22-pound) plastic-lined boxes. The top layer of squid in these boxes was found to be frozen and the remainder was unfrozen. These squid had been stored in ice water prior to packaging. The unfrozen squid were sorted into three groups by mantle length before being fed into the machine. The groups were: 80-110 mm (3.2-4.4 inches), 110-150 mm (4.4-6 inches), and 150+ mm (6+ inches).

Frozen whole squid were thawed, drained of excess water, and weighed before being fed into the machine. The output of the machine was also drained and weighed. The yield by weight consisted of cleaned mantles and severed tentacles (beak not removed) drained of water. In 22-25 percent of the sample output the viscera were still connected to the body by a thread of tissue even though the viscera had been removed from the body cavity. These viscera and bits of skin could be separated easily by hand. These squid were included in the yield by weight data. Those squid which were clearly not an acceptable product, i.e., unskinned or uneviscerated, were not included in the yield weight.

[1]Mention of trade names or commercial firms does not imply endorsement by the National Marine Fisheries Service, NOAA.

Results and Discussion

An important parameter in mechanically assisted cleaning of squid is the yield of edible portion. The yield by weight of hand-cleaned squid ranges from 50 to 55 percent according to Ghio[2]. In the tests performed with the pilot-scale machine, the previously frozen squid samples yielded 45 percent edible meat, and the unfrozen samples 52 percent edible meat as shown in Figure 7. The lower edible meat yield in the frozen sample is due to dehydration of the frozen sample during storage.

The dimension of mantle length appears to have a significant influence on processing rates. The unfrozen sample was sorted by mantle length into three size classes. The 110-150 mm (4.4-6 inch) squid, numerically composing 70 percent of the catch, and 72 percent by weight, averaged 51 percent edible meat return as shown in Figure 8. Squid over 150 mm (6 inches), 21 percent of the catch by weight, yielded 58 percent edible meat. Squid less than 110 mm (4.4 inches) yielded 36 percent edible meat. These small squid may not be worth processing since they compose only 14 percent of the catch numerically and only 7 percent by weight. Thus, yield of edible meat from the pilot-scale machine depends on the initial size of individual squid processed. This fact clearly indicates the need to develop a size grading device that would allow the system to achieve high processing rates.

It should be noted that a small portion of the trailing edge of the mantle is cut and discarded in the alignment step. In addition the fins are removed during the skinning step. However, these operations do not significantly reduce the yield since, although these lost pieces are edible, they are very thin in cross section.

The quality of the cleaned squid was evaluated in terms of the desired attributes, e.g., samples completely skinned, eviscerated, and boned. Data in Figure 7 seem to indicate the skinning percentage was higher in the frozen sample. The fresher squid appeared harder to skin. Data presented in Figure 8 indicate that squid greater than 150 mm (6 inches) were very difficult to skin totally; squid less than 110 mm (4.4 inches) were easier to skin. Small portions of fins and/or skin could be easily removed manually. Only those squid from which all of the viscera had been removed by the machine were counted as being part of the fraction totally eviscerated. Figure 7 indicates that 63-73 percent of the squid were totally eviscerated. An additional 22-25 percent of the output was then included in the yield after hand separation of the viscera, removed from the body by the machine but still attached by a thread of tissue. It is clear in Figure 8 how difficult it is to totally eviscerate the squid over 150 mm (6 inches). The evisceration rates in these samples were 33-53 percent. Manual separation was largely feasible in the fraction of these large squid that were not eviscerated totally.

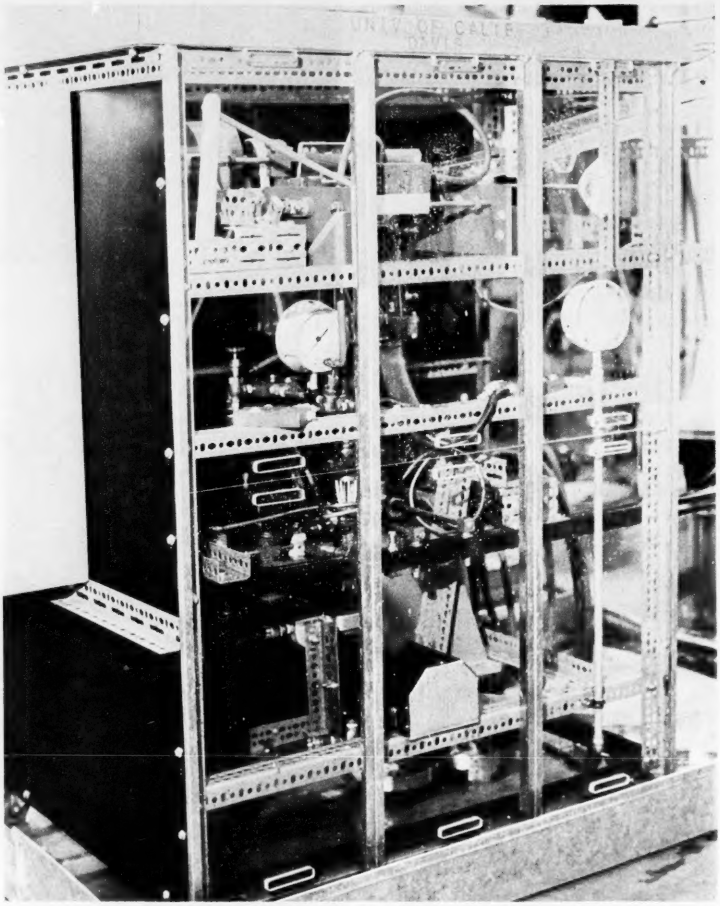

Figure 6.—The squid skinning and eviscerating machine.

[2]Ghio, T. 1979. Ghio Seafood Products, Inc., San Diego, Calif. Personal commun., 10 July.

During processing it was observed that the ink sacs removed with the viscera from the frozen sample came out intact without much ink release. However, in unfrozen samples, a stream of ink flowed with the evisceration water from the interior of the squid. The ink, however, was completely flushed from the squid body cavity, and it did not contaminate or discolor the meat.

A squid was counted as boned totally if the pen was completely removed and not retained by the body or unremoved viscera. The fraction boned totally was high. The pen was at times hung up in the viscera which was out of the body but still attached by a thread of tissue. These squid were not counted as being boned totally and the pens were removed manually.

The cut provided through the squid at the body-cavity opening assisted in severing the attachments for the pen and viscera making them easier to remove. Proper alignment ensured that this cut was made with the minimum loss of edible meat. Inspection of the output from the machine indicated that the fraction of squid aligned properly for cutting knives was very high. The proper cut was made in at least 80 percent of the squid fed into the machine. The data for unfrozen, sorted squid show that squid over 110 mm (4.4 inches) were aligned at an 84-88 percent rate (Fig. 8). Squid under 110 mm (4.4 inches) were aligned at a significantly lower rate (47 percent) in this sample. In addition, they were boned at a slightly lower rate (68 percent vs. 78 and 79 percent for the 110-150 and 150+ mm (4.4-6 and 6+ inches) squid, respectively). However, in the 80-110 mm (3.2-4.4 inch) sample the squid were headed, skinned, and eviscerated at a high rate compared with the other size ranges. Their smaller size probably makes them easier to skin and eviscerate, despite improper alignment.

Flesh firmness also had an effect on the frequency of alignment. Squid bodies that were not firm were not engaged properly by the alignment pins. The edible meat loss was then higher than necessary.

Water consumption rates were measured in operating the pilot-scale

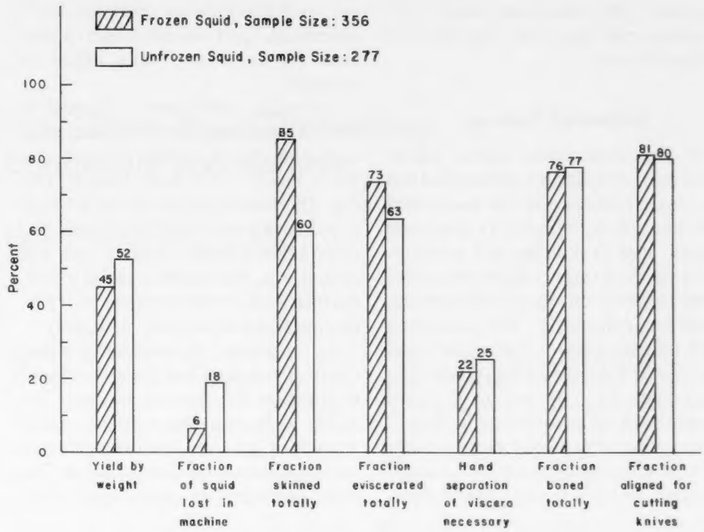

Figure 7.—Processing data for frozen and unfrozen squid.

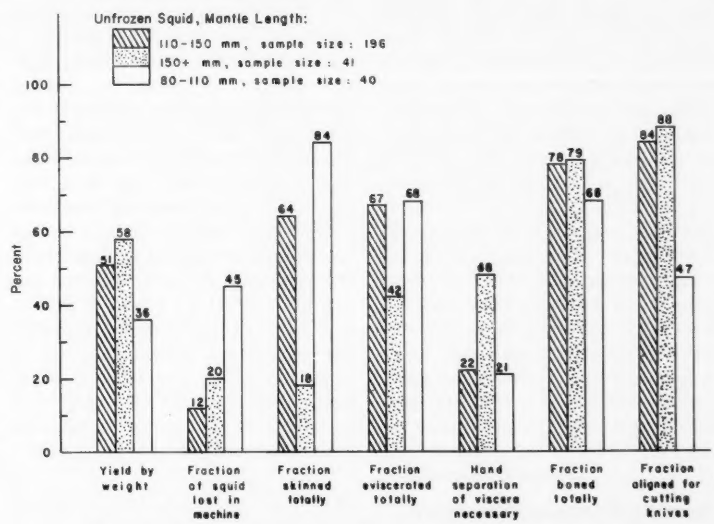

Figure 8.—Processing data for unfrozen squid sorted by mantle length.

machine. The maximum water consumption rate was 0.38 *l*/second (6.0 gallons/minute).

Industrial Scale-up

In an industrially-viable squid-processing machine it is anticipated that the single channel unit can be divided into two stages, namely, 1) alignment trough, and 2) skinning and evisceration peg. Each stage could be controlled independently and thus could process squid simultaneously. The processing time for each stage is 7-8 seconds and this would have the effect of doubling the output from its current 4 squid/minute or 18 kg/hour (40 pounds/hour). The number of pegs and troughs could then be multiplied to get the required tonnage. Using a 6 squid/pound average, an 8 squid/minute operation, and a processing goal of 10 tons/8 hours, from 30 to 35 peg units would be required.

Hydraulic conveyance of squid to each of these units can be accomplished with a fluidized ducting system of a 38-51 mm (1.5-2.0 inch) diameter tubing. This has been tried on a small scale in our laboratory. Squid were separated from a batch loaded holding tank and ducted to another location one at a time. Further work on this component of processing squid is currently underway.

In summary, a pilot-scale squid cleaning machine has been developed to automate the cleaning process. The edible yield from the machine, 45-52 percent of the total body weight, was comparable to hand-cleaned squid. The yield depended on initial size of the individual squid and prior handling operations. The processing efficiency was highest for squid with a body length of 110-150 mm (4.4-6 inches). The pilot-scale machine forms the basic unit around which an industrial-scale squid processing machine could be built. The processing rate in the pilot-scale machine was 4 squid/minute or 18 kg/hour.

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"Saki-ika": Dried Squid Processing Equipment and Markets

DANIEL J. SHEEHY and SUSAN F. VIK

Introduction

Squid has been widely recognized as an underutilized food fishery in the United States. Only 18,700 t were landed by domestic vessels in U.S. waters during 1978, yet the potential annual yield has been estimated at about 390,000 t (Gulland, 1971). United States fishing efforts for squid usually occur in inshore waters within 19 km (12 miles) of the coast. A small directed fishery exists in California, where 91 percent of the total 1978 domestic catch was landed. Kato and Hardwick (1975) have described the various methods used to capture *Loligo opalescens*, the principal species landed off the U.S. West Coast. In northwest Atlantic waters, most squid landings are incidental to trawl effort for finfishes (Lux et al., 1974). *Loligo pealei* and *Illex illecebrosus* compose most of the catch (Rathjen, 1973).

American consumer demand for squid traditionally has been low, with domestic consumption generally limited to small ethnic markets. Recently, squid has gained some popularity as an entree in California restaurants (Ampola, 1974) and a study designed to assess market potential in New England has been started (Rathjen, 1977). However, neither development has yet had a large impact on consumer patterns. Although a portion of the current catch is canned or frozen for export, primarily to Europe and the Philippines (Ampola, 1974), much of the squid harvested by American vessels is used for bait.

In contrast to American consumer tastes, squid is a popular food in many countries in Europe and the Far East and is growing in demand in Southeast Asia (Hotta, 1976). As the demand for squid has exceeded the available supply from their own waters, many foreign fleets have harvested increasingly large amounts of squid from U.S. waters. Squid landings reported by foreign vessels fishing off the U.S. East Coast exceeded 39,000 t in 1977, compared with only 2,500 t taken by U.S. vessels in that area during the same period (Kolator and Long, 1979). However, U.S. adoption of the 200-mile extended jurisdiction, which went into effect on 1 March 1977, has imposed restrictions of squid landings by foreign vessels. As other countries follow the pattern of restricting foreign landings in their own waters, many of the countries where squid demand is high will increasingly turn to imports (Miller et al., 1974).

As an abundant species underutilized for food in the United States but highly prized and increasingly scarce abroad, squid clearly offers great potential as an export product. In the past, however, two factors have consistently been cited as major obstacles to development of the U.S. squid fishery (Ampola, 1974; NEFDP, 1977). No automated equipment capable of splitting, eviscerating, skinning, and processing the squid into a finished product has been known to be available. The laborious, time-consuming procedure for manually cleaning and preparing squid is not economically practical in the United States. Furthermore, no sizable market for squid products has been developed, despite the potentially large export markets. As a result, dock prices are so low that many fishermen do not deem catching squid to be worthwhile. Obviously, these factors are interdependent: Large-scale market development is severely hampered by the lack of automated equipment capable of processing the volume of squid necessary for substantial market demand.

Automated Processing Equipment

In actuality, automated equipment which performs most of the major steps necessary to process squid into a dried form has been in use in Japan for a number of years. By transforming raw squid into a product ready for the supermarket shelf, this machinery both

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ABSTRACT–Dried and seasoned squid products, in a wide variety of forms, are very popular in Japan. Over 400,000 t of raw squid are processed into these products annually. Traditionally processed by hand and sun-dried, most of the processing and drying can now be accomplished with automated equipment. The manufacturing of "daruma" and "saki-ika" two forms of seasoned, dried squid which are not subject to Japanese import quotas, is described. The potential use of this technology for processing American squid for the large Japanese market is discussed.

eliminates the problems inherent in manual processing and also produces a form of squid that is popular among consumers in a country whose squid imports have increased significantly since 1976—Japan (Iida, 1978).

This paper will describe some of the Japanese dried squid products, the automated processing and drying equipment developed by the Japanese, and potential uses of such equipment in the United States. It will also assess the advantages of exporting seasoned dried squid to Japan, and will suggest possibilities for market development for seasoned dried products in this country.

Japanese Dried Squid Products

Traditionally, squid was eaten in Japan in a sun-dried form called "surume." Although improvements in freezing and cold storage facilities during recent years have made fresh or frozen squid more readily available to Japanese consumers, seasoned and unseasoned dried squid continues to be very popular. In 1977, approximately 400,000 t of raw squid were converted into a variety of dried and seasoned squid products. While the sun-drying method is still used in some rural areas of Japan, it has been virtually replaced by the use of automated equipment, which is not only considerably faster and more efficient but also eliminates the potential for spoilage due to less than ideal weather conditions.

The general procedure for preparing dried squid products consists of splitting and eviscerating the raw squid; removing the ink sac, cartilage, and skin; and drying the mantle, arms, and fins. Depending on the particular type of product desired, the arms and sometimes the fins may be removed and processed separately, seasonings may be added, and the dried squid may be shredded, rolled flat, or shaped. In some products the skin is not removed. Differences in appearance, flavor, texture, and moisture content distinguish the various types of dried squid products.

A number of terms, some with overlapping meanings, are used by the Japanese to describe the different types of dried squid products. "Chimmi," a general Japanese term for any seasoned and prepared seafood product, is combined with "ika," the word for squid, to refer to processed squid products. "Daruma" designates a slightly seasoned, semi-dried intermediary form consisting of skinless mantles with fins, from which various types of "chimmi-ika" are processed.

Popular types of "chimmi-ika" are "surume," "saki-ika," and "noshi-ika." "Surume," previously used to refer to sun-dried squid, now denotes unseasoned dried squid, either whole or with mantle and fins only. "Surume-ika" is also the Japanese name of the particular species, *Todarodes pacificus*, that once constituted up to 90 percent of the Japanese domestic squid catch. (Before the advent of freezers and automated processing equipment, "surume-ika" and "surume" were virtually synonymous and even today are often used interchangeably.) "Noshi-ika" consists of mantles with fins that have been flattened, stretched, and softened by rollers. Seasoned and shredded mantles are referred to as "saki-ika."

"Chimmi-ika" are popular snack foods in Japan and are enjoyed on the same types of occasions as are potato chips or salted peanuts in the United States. Among adults, "chimmi-ika" are particularly favorite accompaniments to sake, beer, and whiskey. Their texture ranges from mild to sweet to spicy; their texture, from crisp to chewy. They usually are packaged in plastic bags and are commonly marketed in stores, restaurants, bars, and vending machines.

Manufacture of "Saki-ika" and "Daruma"

The equipment and procedures used to produce "saki-ika," with "daruma" as an intermediary product, are typical of the automated technology currently used to produce a number of Japanese dried marine products. Some of this equipment can be used in the production of other squid products and, with minor modifications, can also be used to process fish fillets, such as Alaska pollock, which are popular in Japan and other Asian countries.

Either fresh or frozen (whole or split and cleaned) squid can be used as the raw material for this processing. In earlier times, "saki-ika" was traditionally made from "surume." Since this product (called "hard saki-ika") is difficult to chew, almost all of the current production is made from foreign frozen squid. Some imported "daruma" is also being used as the raw material.

The processing procedure is outlined below. A system of net and belt conveyors transfers the squid from one stage of the process to the next in a fully automated plant. In areas where labor is less expensive, some conveyors and machines, such as the splitters and coolers, can be eliminated. As a result, the processing time increases and careful attention must therefore be given to the freshness of the squid during the processing.

The yield and moisture content of the squid during the various processing stages are given in Table 1.

Splitting and Cleaning

This process, known as "hiraki," is generally performed with a squid splitting machine. Raw squid are fed anterior end forward into the machine which splits the mantle and removes the head, entrails, and ink sac (Fig. 1a, b, c). The machine can be set to either remove the arms or leave them attached, depending upon the final product desired. For "daruma" or "saki-ika" the arms are removed, leaving a

Table 1.—Yield and moisture content by process stage for the production of 1,000 kg of saki-ika.

Process stage	Yield (kg)[1] Body	Arms	Fins	Avg. moisture content[1]
Whole raw squid	8,000			82
Split, eviscerated squid (arms removed)	4,340	1,600		
Skinned	3,600	1,040		78
First drying	[2]1,368	392		37-38
Roasting (fins removed)	1,232	360		32
Processed product	[3]1,000	319	160	[4]28

Total yield: 1,479 kg (18.5 percent)

[1] Average values based on *Todarodes pacificus* caught near Hokkaido.
[2] "Daruma".
[3] "Saki-ika".
[4] ±1 percent.

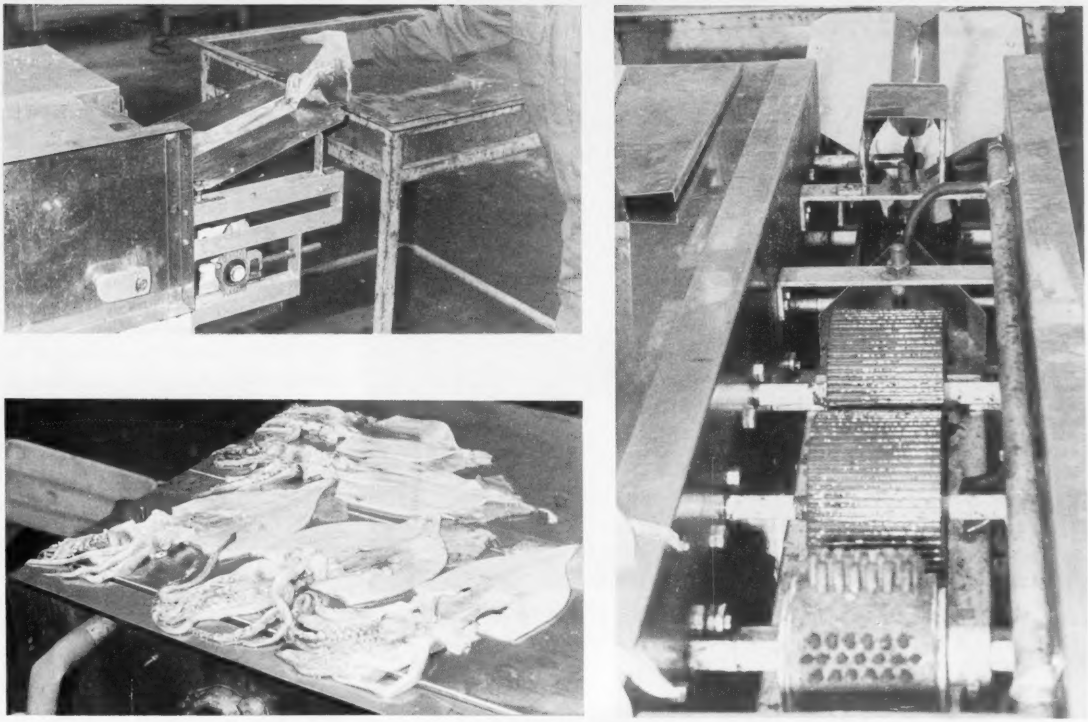

Figure 1.—Squid, at top, are fed into the splitting/cleaning machine. At right is the splitting/cleaning machine showing rotary blade, rollers, and brushes. At bottom are split and cleaned squid (machine was set to leave arms attached).

flat triangular shaped mantle with fins. The quill or pen, where present, is removed manually; this is essential if the end product is to be of the high quality demanded by the Japanese market. A trained operator can process about 3,000 squid per hour.

The entrails are used as fertilizer or bait and the eyes are used in the production of luminous dials. The arms are processed in a similar manner and are packaged and sold separately as "geso."

Washing

Prior to skinning, the squid is washed to ensure that the final product is of high quality. A continuously operating rotary washer with a capacity of 4,500 kg (9,900 pounds) is used. When used with a conveyor system, this process is completely automated.

Skinning

Once they have been washed, the squid are transferred to skinning machines supplied with hot water (Fig. 2). As the hot water blanches the squid, the skin is loosened by the pressure of rapidly circulating water which removes the skin from the flesh without damaging it.

An automatic hot water heater heats the water and regulates its flow to the skinning machine. Water temperature is varied from 50° to 65°C, depending on the freshness of the squid. Selecting the correct temperature is an important factor in product quality. If the water is too hot during the initial stage of the process, spots form on the mantle and the flesh shrinks; if it is tepid near the end of the process, the flesh will become thin when dried, resulting in poor yield. Generally, 50 percent of the water is replaced twice during the operation. When the skinning process is complete, the squid are agitated in the machines in water 70°-80°C for about 3-5 minutes, and then are placed on a net conveyor.

Cooling

Rapid cooling is necessary after the squid are skinned and heated. Rotary cooling machines which spin the squid through air and cool water are generally used. As an alternative, the squid can simply be placed in tanks of cool water (Fig. 3).

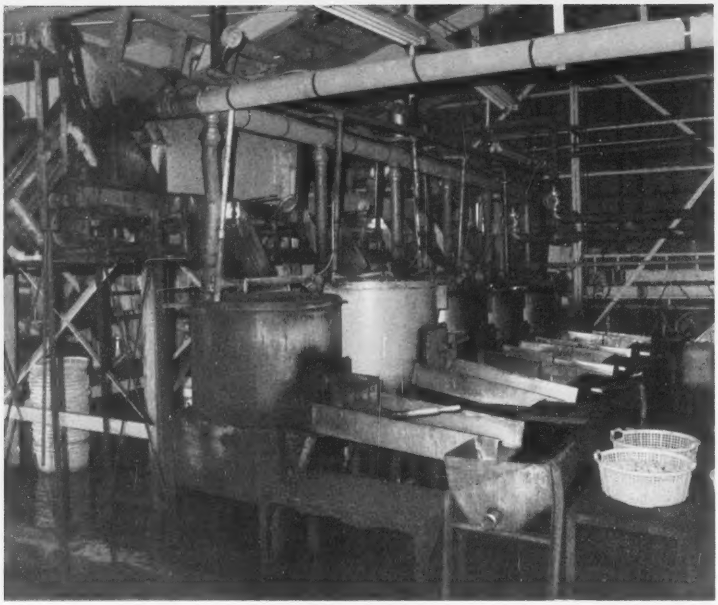

Figure 2.—Squid skinning machines. Squid enter via net conveyor at top and exit via chute at bottom.

Figure 3.—Squid are removed from cooling bath after skinning (press roaster in background).

First Seasoning

The cooled squid is automatically weighed and a proportionate amount of dry powdered seasoning, pre-mixed in a rotary mixer, is added to it via a constant-speed conveyor belt. Although the exact composition of the seasoning varies, it usually includes salt, natural sweeteners, spices, ascorbic acid, sugar, monosodium glutamate, and other flavoring agents.

The squid and seasonings are placed in polyethylene containers for a minimum of 4-6 hours. In actual practice, they usually remain there overnight for convenience. During this time fluids released from the squid mix with the seasonings to form a solution. If room temperature exceeds 25°C, the squid must be stored in a refrigerated room to prevent a spontaneous fermentation which reduces quality and yield.

First Drying

The squid are drained, placed on nylon mesh racks (Fig. 4), and put in an air drying unit in which a temperature of 40° C is maintained by a fully automated oil burner and air circulation system. After 8-10 hours of drying the moisture content is reduced to about 37-38 percent. This partially processed squid mantle (with fins) is known as "daruma." It can either be marketed at this point to a processor and later processed into other forms, or it can be immediately processed into a finished product such as "saki-ika."

A description of the process necessary to produce "saki-ika" follows.

Press Roasting

The squid ("daruma") is fed into press roasters and pressed for 10-15 minutes between two conveyor operated heated plates. The temperature of the plates, running speed, and roller spacing of these presses can be adjusted to accommodate a wide variety of sizes and species.

Removal of Fins

The fins and top of the mantle are removed manually. They are then processed separately and marketed as "mimi."

Rolling

The mantles are fed into a roller press and flattened (Fig. 5).

Shredding

The flattened mantles are hand-fed into a shredder in which two sets of blades shred the mantle into strips. Usually the strips are about 3 mm (0.12 inch) in width (Fig. 6), but for "ultra saki-ika" the strips are 5 mm (0.2 inch) in width.

Second Seasoning

The shredded mantles are seasoned for a second time in a rotary mixer (Fig. 7). Alcohol diluted with water is sprayed over the squid to liquify the seasoning so that it will soak into the squid. The squid is held in polyethylene containers for 4 hours. Again the particular composition of the seasoning varies according to the desired flavor for the final product.

Second Drying

During the second drying process an infrared drying unit is used to bake in the seasoning which coats the squid with a film that aids in retarding spoilage. The moisture content is reduced to about 28 percent. The product is now "saki-ika" (Fig. 8).

Packaging

Additional seasonings and additives, generally in an ethanol base, may be added to the "saki-ika" during packaging. Salt and active water (potassium sorbate, sodium metaphosphate, and acetic acid) are also added to prevent color changes and to adjust the pH to between 5.9 and 6.0 in order to retard mildew formation. Expected shelf life of "saki-ika" ranges from 60 days to 6 months. The final product is generally packaged in attractive clear plastic bags with the "saki-ika" readily visible to the consumer (Fig. 9).

Discussion

The National Marine Fisheries Service has been evaluating the potential for developing a food fishery for American squid, particularly on the U.S. East Coast, for some time. Studies

Figure 4.—Squid tentacles are placed on drying racks.

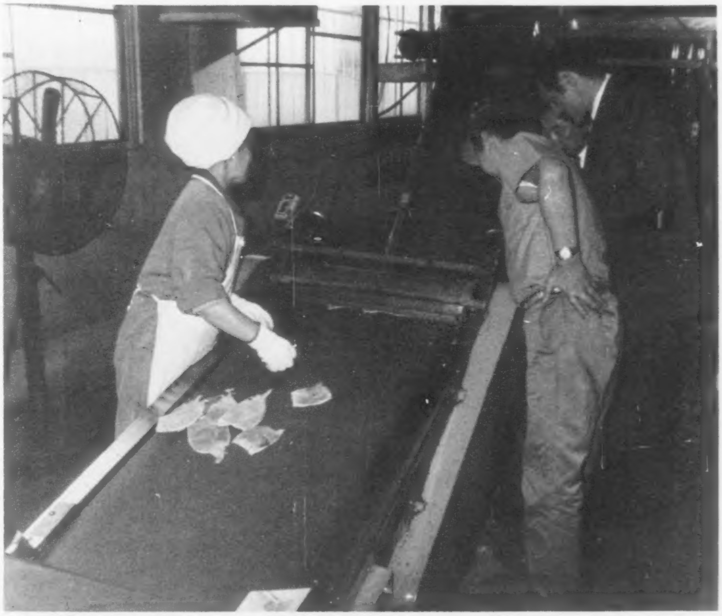

Figure 5.—Flattened squid mantles come off roller press.

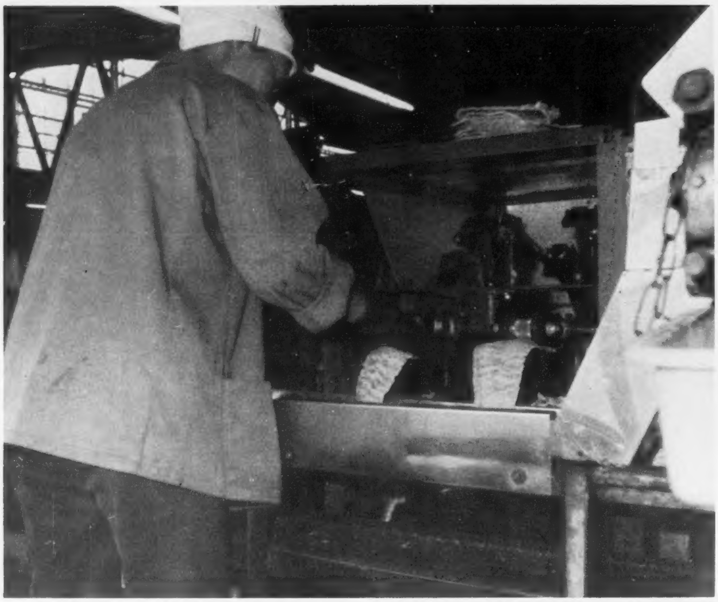

Figure 6.—Squid mantles are fed into shredding machine.

Figure 7.—Seasoning squid for the second time in a rotary mixer.

of the biology and stock status of squid off the northeast coast have been conducted (Lange, 1978; Tibbetts, 1977; Tibbetts-Lange and Sissenwine, 1977), and basic models designed to simulate the effects of fishing on these stocks have been developed (Sissenwine and Tibbetts, 1977). A number of studies have identified squid as a major underutilized resource (Ampola, 1974; Lux et al., 1974; Rathjen, 1977) and one which has considerable potential for export (Miller et al., 1973; McAvoy and Earl, 1977). Recent studies of the care and maintenance of squid quality (Learson and Ampola, 1977) and foreign fishing operations off the East Coast (Kolator and Long, 1979) have provided valuable information about squid fishing practices and proper handling of squid at sea.

Processing dried squid in the United States for export to Japan and other Asian countries offers a number of advantages. Most importantly, it would make possible the development of a U.S. squid fishery on the East Coast. Introduction of the Japanese automated processing technology would address the two major factors most often cited as reasons for the current underdevelopment of this fishery: Lack of processing equipment and lack of a substantial market (NEFDP, 1977). The Japanese technology provides the means to produce squid products which are popular and expensive in Japan.

Approximately 600,000 t of squid are consumed annually in Japan, which has the highest consumption (both per capita and total volume) of squid in the world. About 50 t of dried squid products, including 30 t of "saki-ika," are eaten daily. Faced with declining domestic catches and increasing restrictions on its distant water fisheries, Japan began importing squid in 1976 (Iida, 1978). The total amount of squid imported in 1978 was over 122,000 t, worth about $240 million; this represents a 36 percent increase over the figures for 1977. While the Japanese Government restricts squid imports through a system of import quotas, these quotas have recently been liberalized; "daruma" and "saki-ika," as well as some other processed pro-

ducts are not subject to quota restrictions.

Exporting squid in a dried form offers several specific advantages. The quality of squid required for the production of some forms of dried squid is not as stringent as that for other products. Frozen trawl-caught squid can be effectively used. In addition, shipping costs (a major consideration in exporting) for dried squid products are significantly lower per value unit than for fresh or frozen squid, due to the reduced volume and weight.

Processing squid in the United States would add considerable value to the catch, employ Americans, and contribute to easing the trade deficit with Japan. The recent devaluation of the dollar with respect to the yen has made American products more attractive to Japanese buyers. A new law passed in 1978 amends the 1976 Fishery Management and Conservation Act and gives American companies the first chance to process fish caught in U.S. waters by American fishermen. This has served to increase the cooperative relationships between U.S. and Japanese fishing interests as evidenced by the increase in U.S. seafood exports to Japan (Kaplan, 1979). The use of this processing technology and equipment could assist in bridging the gap between the resource and the buyer, and help eliminate the problem of variations in product quality which has hindered earlier attempts to enter the Japanese market.

A product such as ''saki-ika'' may also have potential for introduction into the U.S. market as a high protein snack food. The final product does not resemble whole squid and the taste can be adjusted by altering the seasoning. It is somewhat similar in both taste and texture to the popular beef jerky sticks currently available on the U.S. market.

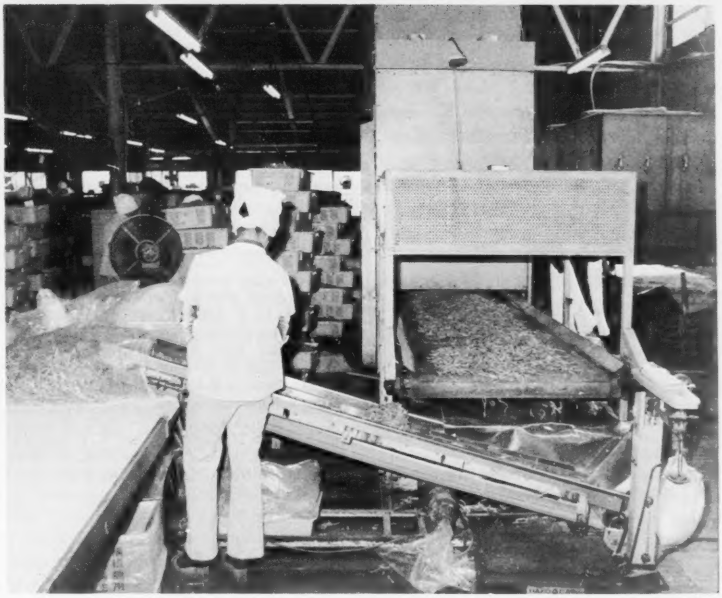

Figure 8.—Shredded and seasoned squid come out of the infrared dryer and are bulk packaged.

Figure 9.—Final packaged product among a variety of dried products at a wholesale market.

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